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An Investigation of Salmonine Reproduction and Factors Limiting Their Production in Sandy Creek, Monroe County, New York

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An Investigation of Salmonine Reproduction and Factors Limiting Their Production in Sandy Creek, Monroe County, New York

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Abstract

Sandy Creek is stocked annually with salmonines by the New York Department of Environmental Conservation. A good recreational fishery has been established during fall spawning migrations but spawning success and juvenile survival have not been researched. My study sought to 1) determine the extent of use of Sandy Creek by adult and juvenile salmonines in 2006 and 2007, 2) assess the creek's potential for sustaining spawning and early life history requirements, and 3) estimate salmonine production in Sandy Creek and potential recruitment to Lake Ontario. Adult Chinook and coho salmon, brown trout and rainbow trout/steelhead were captured and spawned in Sandy Creek. Suitable spawning habitat is generally restricted to the upper reaches of Sandy Creek's east and west branches because bedrock and mud substrates preclude redd construction elsewhere. Habitat and physiochemical conditions are conducive for healthy egg and larval development through winter and spring. Juvenile Chinook and coho salmon, brown trout and rainbow trout/steelhead caught in Sandy Creek were mostly in the east and west branches. Chinook salmon grew rapidly, reaching a total length of ~100 mm between emergence in March and out migration to Lake Ontario in June. Coho salmon and rainbow trout/steelhead occupied the headwater region of the east branch of Sandy Creek; few juvenile brown trout were captured. Water temperatures exceeded the upper thermal thresholds (>28 °C) of most salmonine species throughout most of Sandy Creek during July and August. Areal extrapolation of CPUE suggests that Sandy Creek can produce ~6,900 juvenile salmonines/creek ha but only the

headwater regions provide suitable habitat and physiochemical conditions for salmonine survival year round. Reforestation of the riparian zone and subsequent decreases in soil erosion and summer water temperature would increase salmonine production in Sandy Creek; however, the predominantly bedrock substrate prevents spawning in 90% of its main stem. Sandy Creek also supports a healthy, diverse warmwater fish community.

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Introduction

Lake Ontario fishery and salmonine stocking history

The Lake Ontario fishery has experienced substantial change and manipulation throughout its history, all a direct result of anthropogenic activities (Jude and Leach 1999). Examples are connection to the Atlantic Ocean via canals; extreme modifications of its drainage basin, watersheds and tributaries causing habitat destruction; the establishment of exotic species, most notably sea lamprey (*Petromyzon marinus*) and alewife (*Alosa pseudoharengus*); physical and chemical changes due to urbanization, agriculture and industry; and intense selective and destructive fishing practices.

Lake Ontario may have supported the largest Atlantic salmon (*Salmo salar*) population in the world (Smith 1985); it provided a sizeable Atlantic salmon fishery from the late 1700s until the middle1800s. However, populations declined rapidly in the 1870s, and the last Atlantic salmon was extracted from Lake Ontario in 1898 (Smith 1995). This collapse occurred quickly due to intensive fishing and tributary and watershed damage. Industrial pollution, deforestation, and the damming of spawning run passages relegated many of Lake Ontario's tributaries useless for salmonid reproduction; by 1845, 7,406 water-powered sawmills were operating in the state of New York (Smith 1995, Connor et al. 2002). Dam construction can destroy populations, especially if spawning and rearing habitats are eliminated or migration corridors are blocked (Connor et al. 2002).

Throughout the decline of the Atlantic salmon fishery in Lake Ontario, lake trout (*Salvelinus namaycush*), and whitefishes (*Coregonus* spp.) were depleted in near shore habitats, initiating a shift of the fishery to deeper waters where lake herring (*Coregonus artedii*) also comprised part of the commercial catch. This deep water commercial fishery for lake trout, lake herring and other whitefishes was successful until the 1930s when it collapsed. Sea lampreys, first sighted in Lake Ontario in 1835, became abundant in the early 1900s when deforestation created ideal stream conditions for lamprey reproduction through warming water temperatures and eroded soils replacing hard stream substrates (Smith 1995). Lamprey parasitism on commercially important fishes became additive–as each new fishery species was exploited by humans and declined, lampreys and humans preyed on the next species with the largest individuals (Smith 1985).

Alewives were first reported in Lake Ontario in 1873, and their population exploded through the 1960s as their predators (Atlantic salmon, lake trout, burbot [*Lota lota*]) declined. There has been a decline of many valuable fish species and greatly reduced fishery productivity in the Laurentian Great Lakes where alewife has become the dominant species (Smith 1970). Commercial fishing declined or ended in United States waters due to poor productivity, and the Great Lakes Fishery Commission was created in 1955 to control sea lampreys and coordinate stocking of salmonines to reduce alewife populations (Smith 1995). Salmonine stocking began in Lake Ontario in 1970, and TFM (a sea lamprey larvicide) treatments began in Lake

Ontario tributaries in1972, at which time the average salmon or trout had a dozen or more lamprey scars (Smith 1985).

Since the 1960s the alewife has been the keystone ecological species in Lake Ontario; they are effective egg/larvae predators and zooplankton food competitors that displaced all other Lake Ontario species at the same trophic level and they comprise 80-90% of stocked salmonine diets (Smith 1970). The initial introduction of salmonines into the Great Lakes in the 1970s was an attempt to control nuisance levels of alewife but quickly became focused on developing a multi-million dollar recreational fishing industry (Stewart 2002). Primary introductions failed to establish significant fisheries due to high parasitic sea lamprey-induced mortality; however, in the early 1980s sea lamprey were effectively controlled by chemical treatments of their nursery areas and survival of all stocked trout and salmon improved (Stewart 2002). The number of salmonines stocked in Lake Ontario and its tributaries rapidly increased throughout the 1970s and 1980s. In the mid-1980s the state of New York and the province of Ontario agreed to limit stocking to 8 million salmonines annually in response to concerns about the sustainability of the high predator levels, declining alewife, record fishery yields, and perceived risks to the burgeoning recreational fishery (Kocik and Jones 1999). In 1992, and again in 1996, joint New York and Ontario technical syntheses and stakeholder consultations resulted in changes to stocking policy (Stewart 2002). Salmonine stocking levels were reduced to 4.5 million fishes in 1996, and have been maintained at 4 and 5.5 million fishes annually. In 1999, the percentage of the total salmonines stocked by species was 39.2%

Chinook salmon (*Oncorhynchus tshawytscha*), 18.8% lake trout, 17.2% rainbow trout (stream resident life strategy)/ steelhead (anadromous/migratory life strategy) (*O. mykiss*), 12.2% brown trout (*Salmo trutta*), 7.2% coho salmon (*O. kisutch*), and 5.5% Atlantic salmon (Stewart 2002). Two of the most successful colonizers of Great lakes tributaries were stream resident brown trout and anadromous rainbow trout/steelhead; these species have developed self sustaining anadromous populations throughout the Great Lakes basin (Kocik and Taylor 1996).

Sandy Creek, Monroe County, New York, is classified as a medium use tributary for salmonine angling by the New York Department of Environmental Conservation (NYDEC). The Lake Ontario tributary survey (Prindle and Bishop 2006) estimated that 15,818 angler hours were spent on Sandy Creek in 2006 during 4,105 trips; 43.1% of the anglers were non-NYS residents. NYDEC salmonine stocking levels in Sandy Creek and off nearby Hamlin Beach State Park reflect the importance of this tributary to both regional and out of state anglers. Fishes stocked at Hamlin Beach most likely home to Sandy Creek to spawn. In 2005 the NYDEC released 35,360-14 cm brown trout, 10,700-20 cm brown trout, 11,760-24 cm brown trout, 14,760-21.5 cm rainbow trout/steelhead, and 6,140-23 cm rainbow trout/steelhead at Hamlin Beach. Also in 2005, the NYSDEC stocked 129,370-7.5 cm Chinook salmon, 26,000-13 cm coho salmon, and 14,650-13 cm rainbow trout/steelhead in lower Sandy Creek (NYDEC 2006).

In New York Chinook and coho salmon move into spawning streams during September and October; 1,525 Chinook and 41 coho were caught by anglers in Sandy

Creek during the fall of 2006 (Prindle and Bishop 2006). Although Lake Ontario and Sandy Creek harbor a successful recreational fishery, it is predominantly a put (stock), grow and take fishery; the contribution of naturally produced salmonines in Lake Ontario tributaries is not well understood. The intensity and frequency of NYDEC salmonine stocking in and near Sandy Creek and the homing of salmonines to their natal or stocking stream to spawn provides an opportunity to study salmonine spawning activities, subsequent survival of eggs and fry, and the suitability of Sandy Creek as a salmonine spawning and rearing tributary.

Objectives

The objectives of my study were to 1) compare the physical habitat characteristics of Sandy Creek to known early life history requirements of Chinook and coho salmon, brown trout and rainbow trout/steelhead, 2) determine locations suitable for salmonine spawning and juvenile survival in Sandy Creek, and 3) locate impassable barriers which restrict access to potential spawning and rearing habitat. Related objectives included determining which salmonine species spawn in Sandy Creek, documenting their spawning acts and redd sites, quantifying fry emergence from a subset of redds, and documenting the survival of juveniles through the summer months while studying the habitats that permit survival.

Important questions that this study aimed to address were: Which factors, if any, limit successful reproduction and recruitment of trout and salmon in Sandy Creek? Is there enough habitat for substantial numbers of salmonines to spawn and survive in Sandy Creek? Do salmonines spawn in marginal or poor habitats in Sandy Creek? Which habitats in Sandy Creek harbor juveniles through early life stages? Do juvenile salmonines survive the warm summer months in Sandy Creek?

Study area

Sandy Creek has two branches, a main stem, and a drowned river mouth at its confluence with Lake Ontario. The west branch originates in the Town of Barre, NY and flows north. In the Village of Albion the west branch transitions to an easterly flow after passing beneath the Erie Canal from which it receives water. The east branch of Sandy Creek emerges in Clarendon, NY and flows in a northeasterly direction. The east branch is dammed in Holley, NY where it is retained in a ~1.5 acre pond. Further downstream this branch is diverted into a culvert beneath the Erie Canal and receives water from the canal. At Route 104 the east branch hooks west and joins the west branch just south of Route 104 and west of Route 237 to form the main stem of Sandy Creek. Sandy Creek's main stem flows northeasterly through the Town of Kendall, NY; it ends as a drowned river mouth at its confluence with Lake Ontario in the Town of Hamlin, NY (Figure 1).

During the spring, summer and fall seasons, the Erie Canal contributes water, sediment and fishes to Sandy Creek. The canal is drained from November to April. During the drawdown, large volumes of water are released from the canal into Sandy Creek, which likely helps adult salmonines migrate upstream.

Due to diverse rural, suburban and urban communities, there are multiple land uses in the Sandy Creek watershed. Farmland covers over 57% of the watershed in the form of cultivated croplands, orchards and dairy farms. Numerous farms utilize Sandy Creek for the irrigation of crops and a few for watering cattle. Successional and mature hardwood and conifer forests also punctuate Sandy Creek's watershed, providing habitat for mammals such as White-tailed Deer (*Odocoileus virginianus*), Beaver (*Castor canadensis*) and Red Fox (*Vulpes vulpes*) and birds such as Pileated Woodpecker (*Dryocopus pileatus*), Great Blue Heron (*Ardea herodias*), Red-tailed Hawk (*Buteo jamaicensis*) and Belted Kingfisher (*Megaceryle alcyon*) (personal observation). Sandy Creek also flows through two villages (Albion and Holley) and past many rural private residences.

The aquatic habitats within Sandy Creek are as varied as the land uses in its watershed; the east branch, west branch and main stem each exhibit unique habitats. The west branch typifies a headwater stream; its substrate is consistently firm and varies in size from pea gravel to large boulders. The channel is narrow and shallow with significant flow, averaging 1 m/s. Cooler water temperatures exist in the west than in the east branch and main stem, probably due to a predominantly forested watershed and consistently dense canopy cover. There is very little siltation and few rooted aquatic macrophytes in the west branch. The amount of in-stream wood varies throughout this branch, with much of it in log jams where the branch narrows or bends, creating deeper pools among the riffles and runs that dominate the west branch. The soils and the creek banks of the west branch are rocky and stable, and the greatest creek gradient occurs within this branch.

The aquatic habitat of the east branch is primarily determined by the easily erodible soils and land uses within its watershed. This branch has little gradient, sluggish flow, high turbidity and high temperatures downstream of the Erie Canal. Much in-stream wood is found in this branch due to bank erosion, and the resulting log jams carve deep pools in the soft substrate. Aquatic macrophytes are prevalent in the east branch due to less canopy cover, slower flow and favorable rooting substrate. Upstream of the canal the remaining small portion of the east branch changes to a high gradient, rocky substrate.

The main stem of Sandy Creek has rocky and bedrock substrate with wide channels, mostly shallow depths and moderate flows. Water temperatures are often high and canopy cover is varied. It harbors many macro- and microhabitats, including large, shallow pools connected to wetlands with extensive aquatic macrophytes. The last kilometer of the main stem is a drowned river mouth bordered by cattail marshes, marinas and private homes.

Salmonine life history requirements

Populations of Great Lakes salmonines are made up of semi-discrete stocks that exhibit local adaptations (Kocik and Taylor 1996). The four predominant stream-spawning salmonine species in Lake Ontario tributaries are Chinook and coho salmon, brown trout and rainbow trout/steelhead. While all of these species migrate upstream in Sandy Creek to spawn, hatching and emerging success of alevins, as well as survival of juveniles to smoltification, are unknown. In contrast, the state of Michigan now estimates that nearly 40% of the Chinook salmon entering the Lake Michigan fishery originate from natural reproduction and that significant reproduction of coho salmon, rainbow trout/steelhead and brown trout is occurring in all accessible sections of rivers with good water quality (Lynch 2002).

Chinook and coho salmon, brown trout and rainbow trout/steelhead home to and ascend their natal streams to spawn, although there is some straying. Chinook and coho salmon are semelparous, while rainbow and brown trout are iteroparous. In most cases mature adults select a site with a gravel substrate and a substantial flow of cold, clear, well oxygenated water. Spawning salmonines generally prefer locations with small to medium sized gravel at the head of a riffle where smooth water of the upstream pool begins to roughen as it flows over the riffle (Werner 1980). The female of each species excavates a redd (nest) by facing upstream while lying on her side and vibrating her body, kicking out gravel which is carried a short distance downstream. The process is continued until a depression several inches deep is created; the female will frequently lie on the redd, extending her anal fin as if to measure the correct depth during the excavation phase (Werner 1980). The male stands guard during this process, chasing other fish away. When the female is satisfied with the depth of her redd, the male moves onto the redd with her; she places her vent as close as possible to the deepest part of the redd and extrudes a few hundred to a few thousand eggs (Werner 1980). At the same time the male produces a cloud of sperm that fertilizes the eggs. Frequently more than one male accompanies each female, but one is dominant; the others are accessory males. During fertilization by the dominant male, if other males are still present they usually take advantage of this opportunity and dart into the redd and release sperm (Werner 1980).

Immediately after spawning the female moves upstream and begins to cover the redd by sweeping her caudal fin across the bottom, dislodging gravel which falls into the redd and covers the eggs. Eggs water harden and enlarge, holding them securely within the interstitial spaces of the gravel in the redd. The male guards the redd for a short period of time, but loses interest quickly and abandons his post. Females may carry thousands of eggs and thus may spawn more than once; it has been observed that after spawning a female will frequently move a short distance upstream and begin constructing a new redd (Werner 1980). Egg development time is temperature dependent (Smith 1985). After hatching the sac fry remain in the redd, receiving nourishment from their large yolk sacs. They emerge and begin independent feeding a few weeks to a month later and abandon the redd.

Salmonine egg deposition and survival is strongly affected by both biotic and abiotic factors. Low stream flow during spawning runs promotes overseeding, or intensive spawning activity on limited habitats, which contributes to degradation of inter-gravel water quality by decreasing oxygen and increasing ammonia concentrations due to developing larvae (Kocik and Taylor 1987, Fausch and White 1986). Dead eggs in the substrate also reduce inter-gravel water quality; the associated bacteria and fungi can use up to four times more oxygen than live eggs

(Kocik and Taylor 1987). Trout and salmon have been observed excavating redds on or near the exact spots previously used by other salmonines. This occurrence intensifies as the availability of suitable spawning substrate decreases. Pacific salmons are known to dislodge large numbers of eggs from gravels when superimposing their redds on previously utilized substrate (Greeley 1932). The large, powerful Chinook salmon are temporally and spatially separated (see below) from the other three species during their spawning runs in Sandy Creek; however, if substrate is limiting, coho and brown and rainbow trout/steelhead may disturb Chinook redds when they spawn later in the season.

The survival of eggs and alevins (sac-fry in the redd) during the fall, winter and spring incubation period is intimately linked with stream flows. For them to properly incubate, they need fresh water to deliver oxygen and remove ammonia and other wastes. Generally, the direct impact of stream flow upon the freshwater phase of salmonine life history is in the form of a dome shaped curve; excessive and inadequate flows each have a detrimental impact upon the stock-recruitment relationship (Kocik and Taylor 1987). The critical mean current velocity necessary to remove sand and clay particles from the substrate is 0.3 m/sec, while fine gravel does not begin to move until the velocity reaches 0.6 m/sec (Carl 1982). Dewatering can vary in its detrimental effects upon salmonine redds depending primarily on the amount of residual flow, moisture retention and relative humidity, extremes of temperature, substrate composition and percent fines, dissolved oxygen, alevins' behavior, and other species-specific characteristics such as egg size, deposition depth, and development rate (Kocik and Taylor 1987). High water can also be detrimental to incubating salmonine eggs and alevins. Floods during the incubation stage can wash them out of redds prior to full development, damage them mechanically by shifting redd gravels, or suffocate them with fine silts (Foerster 1968).

Streams with an annual base flow greater than 50% of their average annual daily flow are normally excellent for salmonid production, while streams with an annual base flow substantially less than 50% of their average annual daily flow are normally poor for salmonine production (Carl 1982). Streams controlled by groundwater exhibit stable, constant base flows and temperatures during spawning and incubation periods, while streams controlled by surface runoff are flashy with highly variable flow and temperature regimes and are less suitable for successful salmonine reproduction. However, the major source of oxygenated water in spawning riffles is the flowing stream, not groundwater (Kocik and Taylor 1987).

Abiotic influences in the form of road and bridge construction or logging can greatly affect stream habitats, but management practices such as the utilization of silt curtains may lessen the impact. For example, the bridge over Sandy Creek at Hurd Road was under construction during the winter of 2006-2007. Mechanical destruction or downstream silt loads (depending on stream flow) may have affected redd success.

Salmonine habitat requirements

A study of Lake Michigan tributaries found that most Chinook salmon reproduction, in terms of fry density and occurrence within stream class, occurred in larger trout streams and that Chinook salmon do not reproduce in streams with an average current of less than 0.3 m/sec (Carl 1982). Stream velocities below 0.3 m/sec may be unsuitable for reproduction because of silt accumulation on the stream bed; large streams are more likely to have the minimum necessary water velocity because of lower friction caused by proportionately less bank and bottom in contact with the water (Carl 1982). A greater abundance of fry with increasing water velocity may reflect better conditions for Chinook salmon reproduction as gravels become coarser. Most Chinook salmon in the Great Lakes appear to smolt and outmigrate after two or three months of stream rearing; however, some Chinook salmon out-migrate shortly after emergence in Lake Superior and Huron tributaries (Kocik and Taylor 1987, Fausch and White 1986, Connor et al. 2002). This strategy would be beneficial to juvenile Chinook salmon rearing in Sandy Creek because their outmigration to Lake Ontario would occur before creek temperatures exceed their upper critical temperature threshold of 26 °C during mid to late summer (Werner 1980, NYDEC 2006, Brett 1956).

Coho salmon are often the most numerous salmonine in streams where they occur and are generally found spawning in smaller streams than Chinook, and at higher gradients (Quinn 2005). Most Great Lakes coho salmon smolt after a year of stream residence, but after mild winters some coho salmon smolt and outmigrate only eight months after fertilization (Kocik and Taylor 1987, Quinn 2005, Fausch and White 1986, Sheppard and Johnson 1985).

Brown trout were the most commonly caught salmonine in Sandy Creek during the 2005-2006 fishing season: 5,174 compared to 2,293 Chinook, coho and rainbow trout/steelhead combined (Prindle and Bishop 2006). Brown trout are more tolerant of difficult environmental conditions than the other salmonines utilizing Sandy Creek, tolerating high turbidity and water temperatures for short periods. Brown trout are more likely to reproduce and maintain their population without additional stocking than rainbow trout/steelhead in larger, warmer streams (Brynildson 1963) like Sandy Creek. They can survive upper lethal temperatures of 27-29 ^{o}C and dissolved oxygen levels of 4.5 mg/L during the summer and 2.5-3 mg/L during the winter (Carlander 1997). During spring in the Great lakes age-0 brown trout are found in water averaging 24 cm deep with a mean velocity of 22 cm/s; by summer-autumn they shift to much deeper and faster water (Kocik and Taylor 1996). Brown trout have been observed to spawn in sand and hard clay particles where no gravel was present, frequently near groundwater seepage sites; however, their survival depended on moderate temperatures and low silt loads (Brynildson 1963). Wild brown trout smolt after their second or third summer in streams (Brynildson 1963, Carl 1982, Jonsson 1983). However, many young brown trout migrate to Lake Michigan a few months after emergence and return to their natal streams as yearlings (Carl 1982, Jonsson 1983). Much of the downstream migration of juvenile wild brown trout in the Great Lakes region occurs during May and June before temperatures approach 15 ^{o}C (Hansen and Stauffer 1971).

The rainbow trout/steelhead, unlike other New York salmonines, spawns in the spring; the young emerge later, are smaller during their first year, and occupy different parts of the stream than other salmonines (Fausch and White 1986). Some rainbow trout/steelhead migrate into tributary streams in the fall, but wait until the spring to spawn, while others migrate into streams in March or April (Werner 1980, Rayner 1942). Rainbow trout/steelhead life history is complex, characterized by variable timing of spawning runs, repeat spawning, a diverse diet, and relatively broad habitat requirements (Rand et al. 1993). In Sandy Creek in 2005-2006, 727 rainbow trout/steelhead were caught, ~500 in March and April and ~200 in November (Prindle and Bishop 2006). Due to warmer water temperatures in the spring, the incubation period of rainbow trout/steelhead is shorter than it is for fall spawners: most young hatch within 60 days (Werner 1980). The maximum temperature range of rainbow trout/steelhead is 0 to 28 ^{o}C; however, optimum temperatures are below 21 ^{o}C (Carlander 1997, Brett 1956). Age-0 rainbow trout/steelhead use water averaging 44 cm deep, similar to that used by brown trout; however, rainbow trout/steelhead occupy slower water than brown trout in summer and autumn and suspend in the water column while brown trout have fin contact with the substrate (Kocik and Taylor 1996). Rainbow trout/steelhead in the Great Lakes typically use a stream for more than 18 months (Kocik and Taylor 1996, Sheppard and Johnson 1985, Hansen and Stauffer 1971), but not exceeding the upper lethal temperature threshold is critical to the survival of juveniles in New York tributaries during the summer months.

Both genetics and environment influence rainbow trout/steelhead and brown trout residence and migration patterns (Jonsson 1983). They are the salmonines most tolerant of warm water (up to 28 °C) and, thus, are most likely to survive in the marginal thermal habitats found in Sandy Creek during the summer. In contrast, Chinook and coho salmon have lower thermal tolerances (<25 °C, Brett 1956). The strategy of early outmigration utilized by some Chinook salmon may allow successful recruitment from Sandy Creek, but given multi-year stream residence and intolerance of high temperatures it is unlikely that coho salmon can sustain a wild population in Sandy Creek. Habitat-related flexibility in life history patterns has been demonstrated for several fish species. Experiments with salmonines indicate that smolting and age at sexual maturity vary with changes in the habitat of immature fish (Jonsson 1983).

Methods

Habitat observations and measurements

In the summer of 2006, Sandy Creek was surveyed by wading upstream from its confluence with Lake Ontario to the Erie Canal in Village of Albion and to the dam in the Village of Holley (Figure 1) to locate stream reaches with habitat attributes conducive for salmonine spawning and rearing success similar to those described above. Stream width, depth, velocity, temperature and substrate composition; canopy cover, riparian zone and nearby land use, and creek characteristic (riffle, run, etc.); and instream vegetation and wood were quantified at

40 locations with gravel substrates, 20 purposefully-chosen and 20 randomly-chosen. GPS coordinates were recorded at each sampling site.

Stream width was measured from bank to bank using a 50-m tape; depth was measured from the water's surface to the substrate with a meter stick at ten points along across the creek then averaged. Velocity was measured by floating a 40-mm diameter plastic fishing bobber down the center of the creek over a 3-m distance and computing m/s. Temperature was measured with a thermometer and time of day was recorded. Substrate particle size composition was estimated by walking along a meter tape stretched across the stream, recording distances occupied by various particle size classes (Table 1), and calculating percentages for each substrate size class. Each particle size class was assigned a score and a weighted average was computed to provide one number as an overall index of substrate composition.

Canopy cover was estimated by standing in the center of the creek at each site, looking 25 meters up and downstream, and estimating the percentage of tree canopy overhanging the creek in the 50-m reach. Instream vegetation and instream wood were visually estimated as percentages of bottom cover along a 50-m reach of creek at each sampling site. Instream vegetation was identified if possible. Land use in the riparian zone at each site was characterized for both banks (Table 2), and uninterrupted distance of that land use inland from the stream was estimated. The percentages of run, riffle, pool and waterfall in each 50-m reach were estimated.

A subset of 40 sites with gravel substrate selected from the habitat survey were monitored seasonally (once every three months) from October 2006 through

December 2007 for adult presence, spawning activity, hatching and rearing in Sandy Creek; 20 sites were purposefully-selected for what appeared to be the best salmonine habitat in the creek and 20 sites were randomly-chosen by the Microsoft Excel random number generator tool. Monitoring consisted of searching for evidence of spawning activity (e.g., fish behavior, presence of redds) by walking the creek, attempting to capture young salmonines in fry emergence traps, and backpack electrofishing to find juveniles.

Capture of emerging alevins

I attempted to capture alevins from selected redds with fry emergence traps (Porter 1973). Traps were placed on redds approximately one week before predicted fry emergence. Time of emergence was estimated by first identifying which species built a redd, as suggested by water depth, velocity and substrate size (Meehan 1991) and mean redd area (Reiser 1986). Date of egg deposition was witnessed or estimated. Temperature-dependent incubation periods were calculated by taking temperature measurements in Sandy Creek during the winter-spring incubation periods, and comparing creek temperatures to species-specific development times of rainbow trout/steelhead and brown trout (Embody 1934, Carlander 1997, Quinn 2005) and coho and Chinook salmon (Quinn 2005, Meehan 1991).

Capture of juvenile and adult salmonines

Backpack electrofishing (Halltech HT 2000) and beach seines, (6.4 x 1.2 m and 3.8 x 2.1 m, 0.63 mm mesh) were used during the spring, summer and fall of 2007 at the same 40 sites monitored for spawning activity to quantify young of year and juvenile salmonines and document their habitats. Backpack electrofishing is an unbiased method of sampling juvenile salmonines (Fausch and White 1986) and was employed for 15 min along 100 stream meters at each site. Adult salmonines were captured from the fall of 2006 through spring 2007 employing identical methods at the sites fished for juveniles. On each sampling date at each site, current velocity (m/s, pigmy Gurley meter), temperature (^{o}C) and dissolved oxygen (mg/L) (both measured with a YSI 55 handheld unit) were measured. Water samples for turbidity analysis (NTU) were returned to the lab. Substrate composition was confirmed or amended in relation to earlier estimates.

Watershed analysis

Human activities and land use (e.g., infrastructure, farming, logging, residential) and natural geologic characteristics (e.g., soils, gradient) within watersheds have direct effects on the water quality and substrate composition of water bodies (Figures 2, 3). Land uses in the watershed and riparian zone as well as locations of sampling sites, redds and juvenile salmonines were placed on GIS maps to explore spatial relationships (Figure 4).

NYDEC (2007) tracks hazardous waste sites (RCRA, restoration sites; CERCLA, Superfund sites; and VRI, voluntary cleanup sites) and sites with the potential to contribute sediment loading to the creek through erosion and run off (Figure 5). An impacted sites GIS layer was generated utilizing two data sources: riparian zone and canopy cover data I collected and interpreted orthoimagery (NYSGIS Clearinghouse 2007) (Figure 6). Sites were rated 0, 1, 2 based on potential severity of contributable sediment (Table 3) (Figure 7). Segments were input in ESRI Arc Map 1.5 km upstream of each sampling site waypoint to discover sections of watershed capable of impacting each site through sediment delivery, transport, and deposition. Segments and impacted sites were then layered over NYSGIS Clearinghouse orthoimagery and impacted areas within the riparian zone.

Statistical analysis

For each salmonine species, a General Linear Model (multi-way ANOVA) was used to compare CPUE of juvenile salmonines between purposefully-selected and randomly-chosen sampling sites with gravel substrate and between seasons. Covariates in the analyses were temperature, dissolved oxygen, current velocity, turbidity, substrate composition index number, percent instream wood, bank cover, canopy cover, width of riparian zone, and percent aquatic vegetation. In addition, Best Subsets Regressions were used to identify the sets of habitat factors that best explained the presence of each salmonine species. Detrended Correspondence

Analysis was used to visualize distributions of communities of non-salmonine fishes, also collected in Sandy Creek, in relation to multivariate habitat conditions.

Results

Adult salmonines

During the autumn and winter of 2006, migrating adults of the four stocked salmonine species of interest ascended Sandy Creek. The farthest upstream extent of the three Pacific salmonine (*Oncorhynchus*) migrations was within 1 km of the impassable barriers in the east and west branches; for brown trout (*Salmo*) it was 2 km upstream of the confluence of the two branches (Figure 8). Three coho salmon, 44 Chinook salmon, 30 rainbow trout/steelhead, and 31 brown trout were captured, measured, and released. Scale samples taken from a subset of captured fish indicated that they were 3-6 years old. Adults were captured at 15 of the 20 purposely-selected sampling sites; the other five selected sites were not sampled due to high velocities, depths or turbidities. Adult salmonines were captured at six of the 20 randomly-selected sampling sites; eight of the randomly-selected sites were not sampled due to high velocities, depths or turbidities.

Chinook salmon adults were found throughout the creek system from 1 Sep-15 Nov 2006; however, adults encountered during the month of November had begun senescing. Many Chinook carcasses were observed while monitoring creek temperatures during the winter of 2006-2007. Rainbow trout/steelhead and brown trout were caught at many sites, but they were not as evenly distributed throughout the creek as the Chinook. Rainbows and browns were caught from the drowned river mouth confluence with Lake Ontario to 10 km upstream but were not seen for another 3 km until the confluence of the east and west branches of Sandy Creek. Brown trout persisted in Sandy Creek until late January, and some rainbow trout/steelhead stayed in the creek until August 2007. Two dying female brown trout were observed near the Village of Albion (Figure 1) in November 2006, the victims of head injuries.

In August of 2007, 33 adult rainbow trout/steelhead were discovered while sampling for juvenile salmonines upstream from a beaver dam in the west branch of Sandy Creek; they were in pools excavated by farmers to supply water for irrigation and were tolerating temperatures of 28 ^{o}C. Three had expired before sampling and were given to NYDEC to analyze for Viral Hemorrhagic Septicemia Virus (VHSV); all tested negative (pers. comm., Webster Pearsall, Fishery Manager, NYDEC, Region 8, Avon, NY).

Redds

Salmonine redds were discovered at many sites in Sandy Creek during the autumn and winter of 2006, but I was unable to associate redds with the species constructing them due to lack of water clarity. Forty-four salmonine redds were documented at 13 of the 20 purposefully-selected sites. Three of the purposefully-selected sites did not contain salmonine redds and four could not be sampled due to high velocity, depth or turbidity. Twelve salmonine redds were found at five of the 20 randomly-chosen sites. Seven of the randomly-selected sites did not contain salmonine redds and eight were not sampled due to high velocity, depth or turbidity.

Sites containing large areas of gravel (e.g., 30 m x 10 m) exhibited multiple redds; conversely, sites with only small patches of suitable salmonine spawning gravels (e.g., 5 m x 5 m) rarely contained one redd. The largest group of redds (eight) was located in the Village of Holley upstream from the east branch's diversion under the Erie Canal.

Emergence of alevins

Creek temperatures were monitored during the winter of 2006-2007 to estimate the times of salmonine emergence. Five emergence traps were deployed on 22 Apr 2007 over salmonine redds in Sandy Creek (Figure 9). One of the traps, located at site #79, contained an emergent salmonine on 28 Apr 2007, but it escaped before identification. The only other organisms found in the emergence traps were crayfishes and snails.

Juvenile salmonines

Catches—. Emergent alevins and juvenile Chinook salmon were the most widely distributed salmonine species captured during the spring of 2007 in Sandy Creek (Figure 10). Juvenile Chinook were captured at six of the 20 purposefully-selected sites (N=28) and five of the 20 randomly-chosen sites (N=17). In an attempt to catch out-migrating YOY Chinook salmon, Sandy Creek was blocked at a channel constriction immediately downstream from the Route 19 bridge, the second road crossing upstream of Lake Ontario (Figure 6) in early June 2007, at random times between 7 am and 5 pm, with a 16 m x 2 m, 6 mm-mesh beach seine. No YOY Chinook were captured, probably because the seine was not deployed at night. No Chinook juveniles were caught upstream in Sandy Creek after 18 Jun 2007, indicating they died or migrated to Lake Ontario.

Juvenile coho salmon were caught at only three sites during the spring, summer and fall 2007 sampling period. Coho were captured at two of the purposefully-selected sites (N=12) and one of the randomly-chosen sites (N=10). A yolk-sac fry was one of the coho captured at the random site (Figure 11). Coho inhabiting the randomly-chosen site were found in a tributary roadside ditch that was dewatered by early June of 2007. The purposefully-selected sites harboring coho salmon juveniles were less than 1 km apart, both upstream from the summer inputs of warm water from the Erie Canal (Figure 12). They were high gradient tributaries with temperatures 4-5 ^{o}C lower than the main creek. Coho juveniles persisted at these sites from June through December.

Rainbow trout/steelhead juveniles were collected at four of the 20 randomly-chosen sites (N=8) and two of the 20 purposefully-selected sites (N=35). Two more juvenile rainbows were found at an additional site after access to the creek was granted by Silver Creek Farms, a property that encompasses three miles of Sandy Creek's west branch. Juvenile rainbow trout/steelhead inhabited Sandy Creek in two distinct regions: scattered throughout the west branch and a dense aggregation in a 2-

km reach of the east branch, between the Erie Canal and the Village of Holley dam (Figure 13). Rainbow trout/steelhead juveniles persisted in these regions from June through December, even at stream temperatures of 26 °C in the west branch (several degrees warmer than the 2-km section of East Branch upstream from the Erie Canal).

Juvenile brown trout were found at only three sites, two purposefully-selected (N=8) and one randomly-chosen (N=1). Seven individuals were captured at the purposefully-selected site immediately downstream from the Village of Holley dam (Figure 14) during one sampling effort. Like juvenile rainbow trout/steelhead, juvenile brown trout inhabited the productive site downstream from the Village of Holley dam from June through December. Only two other juvenile brown trout were discovered during the 2007 sampling period, one in the west branch and one near the confluence of the east and west branches.

<u>General Linear Model results</u>—. Catch data for each species was analyzed by a GLM AOV (Statistix 2003) with two treatments (purposefully-selected vs. randomly-chosen sites and spring vs. summer seasons), the treatments' interaction, and ten covariates (temperature, dissolved oxygen, water velocity, turbidity, substrate score, bank cover, canopy cover, width of riparian zone, instream vegetation, and instream wood). No treatment or interaction effects were significant ($P > 0.05$) for any of the four species. Because no Chinook salmon were caught in the summer, the temperature covariate was significant ($P = 0.004$). The in-stream wood covariate was significant for brown trout ($P = 0.002$). No other covariates were significant for the four species (Appendices 1-4).

Best Subsets Regression results—. I attempted to build best subsets regression models (Statistix 2003) to predict juvenile salmonine locations based on the ten habitat variables measured. For Chinook salmon, the three models with the lowest Mallow's C-P values all involved four of the ten habitat measures taken in the study. Because of the significance of temperature in the GLM AOV for Chinook, temperature was forced into the analysis. The model incorporating temperature, instream wood, width of riparian zone, and substrate composition index (C-P = 0.0) explained 24.8% (adjusted r^2) of variation in the results. The model with temperature, bank cover, instream wood, and substrate composition index (C-P = 0.1) explained 24.7% of the variation in the data. The model with temperature, bank cover, instream wood, and substrate composition index (C-P = 0.3 explained 24.3% of the variation in the data. It appears that temperature, bank cover, instream wood, width of riparian zone, and substrate composition explain about one quarter of juvenile Chinook salmon distribution in Sandy Creek (Appendix 1).

For brown trout, the three models with the lowest Mallow's C-P values also involved four of the ten habitat measures taken in the study. Because of the significance of instream wood in the GLM AOV for brown trout, instream wood was forced into the best subsets analysis. The model incorporating instream wood, bank cover, dissolved oxygen, and flow (C-P = 0.5) explained 24.8% (adjusted r^2) of variation in the results. The model with instream wood, bank cover, water velocity, and substrate composition index (C-P = 0.6) explained 24.4% of the variation in the data. The model with instream wood, bank cover, dissolved oxygen, and substrate composition index (C-P = 0.8 explained 24.1% of the variation in the data. It appears that instream wood, bank cover, dissolved oxygen, water velocity, and substrate composition explain about one quarter of juvenile brown trout distribution in Sandy Creek (Appendix 2).

No habitat variables were significant for coho salmon and rainbow trout/steelhead, so none were forced into the best subsets analysis. For coho salmon, the three models with the lowest Mallow's C-P scores (range: -0.3 to 0) again included four of the ten measured habitat variables, but no model explained more than 6% (adjusted r^2) of the variation in coho habitats in Sandy Creek. For rainbow trout/steelhead, the models with the lowest C-P values (range: -0.3 to 0.5) incorporated one to three habitat variables, but no model explained more than 14% of the variation of rainbow trout/steelhead habitats in Sandy Creek. Therefore, the best subsets models for coho salmon and rainbow trout/steelhead (Appendices 3, 4) are not considered further.

Growth—. All salmonine species exhibited similar growth patterns during the study period (March-December). After emerging from redds from late March through late April, juveniles averaged 32 mm. All species grew throughout the late spring and early summer (mid-July) until creek temperatures exceeded 28 °C and growth stopped at 110-120 mm. From the middle of July through December, only two juveniles exceeded 120 mm—two 1-year old rainbow trout/steelhead (212 and 222mm), deemed wild hatched due to lack of stocking marks, were captured in the east branch between the Erie Canal and Village of Holley dam (Figure 12) in late August.

By-catch fish community

Many fish species were caught in Sandy Creek (Tables 4 and 5). Detrended Correspondence Analysis (DCA) was used to distinguish groups of species captured together independent of sampling sites. Axis 1 of the DCA corresponded with the upstream to downstream gradient in Sandy Creek (Figure 15A), with rainbow and brown trout (upstream), northern hogsucker, bluntnose minnow and trout-perch (midstream), and northern pike, brook silverside, alewife, bowfin, black crappie and walleye (downstream drowned river mouth) representing communities along the upstream to downstream gradient. Four groups of species associated with Axis 1 also were associated with Axis 2 (Figure 15A), related to decreasing stream velocity: blacknose dace, creek chub and Chinook salmon; johnny darter, logperch, green sunfish and river chub; yellow perch, brown bullhead and longnose gar; and emerald shiner, golden shiner and greater redhorse. Four pairs of species associated with Axis 1 were associated with Axis 3, corresponding to water temperature: longnose dace and blacknose dace, creek chub and common stoneroller, tadpole madtom and rock bass, and pumpkinseed and eastern banded killifish (Figure 15B). Three groups of species were associated with Axis 3 in relation to Axis 2, corresponding to substrate type: northern hogsucker, bluntnose minnow, green sunfish and central mudminnow; johnny darter, fantail darter, river chub and golden shiner; and trout-perch, logperch, stonecat, golden redhorse and round goby (Figure 15C).

Watershed characteristics

Analysis of the watershed of Sandy Creek, specifically the riparian zone 100 meters from each creek bank, focused on impassable barriers, land use and hazardous waste sites. Impassable barriers to fish migration exist in both branches, 1 km upstream from Route 31 in the Village of Holley in the east branch and 0.75 km downstream from the Village of Albion in the west branch. The barrier in Holley is 2 km upstream from the Erie Canal and the barrier in Albion is 80 m upstream from the Erie Canal (Figure 16).

Over 50 % of Sandy Creek's watershed is actively farmed; however, roughly 20 % of its watershed is covered by forests (Table 6, Figure 4). The Village of Holley is 2 km downstream (north) from the headwaters of the east branch and the Village of Albion is 2 km downstream (north) from the headwaters of the west branch. Both headwaters, and the origin of Sandy Creek where they merge, flow through cultivated land. The confluence of the two branches is 0.5 km upstream (south) from Route 104. Multiple land uses exist between the forested region downstream (north) from Route 104 and the mouth at Lake Ontario which is 8 km north from the Village of Hamlin. Although the majority of land use in this section of the watershed is agricultural, the region downstream from Route 104 until Sandy Creek is crossed by Route 237 is contiguous forest with ideal watershed and riparian characteristics of streams capable of holding trout (Figure 1).

One 2-km section of Sandy Creek's east branch, upstream from the Erie Canal diversion and downstream from the Holley dam (Figure 12), supported more juvenile salmonines than any other section in the watershed. This section is fed by two cool, high gradient tributaries and the pool behind the Village of Holley dam, and its riparian buffer zone is enveloped by forest. It is the only creek section upstream of the two Erie Canal diversions that was not dewatered during the dry summer and autumn of 2007 and the only section of Sandy Creek in which western blacknose dace (*Rhinichthys atratulus*) and longnose dace (*R. cataractae*) were caught (Table 5); these species share the same habitat requirements as most juvenile salmonine species (Page and Burr 1991, Smith 1985). It is also the only creek section in which lethal temperatures for salmonines (Brett 1956) were not exceeded in the summer. Other tributaries to Sandy Creek were ephemeral, drying up in early to mid August in 2007.

Discussion

The objectives of my study were to explore salmonine reproductive success in the Sandy Creek watershed and to evaluate the system's potential for juvenile salmonine production. Three factors influence salmonine reproduction and production: 1) The ability of adults to access areas of the watershed suitable for reproduction, 2) The extent and suitability of substrates for redd construction and larval development, and 3) The extent and suitability of habitat conditions needed by juveniles before they migrate to Lake Ontario.

Adult salmonines

The trend in the numbers of adults of each of the four salmonine species captured during the autumn of 2006 in my study reflected NYDEC stocking patterns in lower Sandy Creek and at nearby Hamlin Beach State Park during 2002-2006 (Prindle and Bishop 2006), but they did not reflect creel survey results (Table 7). Brown trout were caught much more often by anglers in relation to stocking rates.

The amount of rain that fell on Sandy Creek's watershed during the autumn of 2006 was sufficient to flood Sandy Creek over its full bank stage (NOAA 2010, The Weather Channel 2007). This not only allowed adults of all four salmonine species to reach the impassable fish barriers of both the east and west branches of Sandy Creek (Figure 16) but also the adjoining flooded lowlands, road ditches, and seasonally dry tributaries which potentially provided additional spawning habitat (Quinn 2005).

In 2007 a severe drought continued through autumn, and Sandy Creek's bank stage and flow were insufficient to support the migration of adult salmonines to the upper parts of the watershed most suitable for reproduction. A lone Chinook jack was captured 1 km downstream of the east branch's impassable barrier; no other adult salmonines were captured or observed upstream of Sandy Creek's drowned river mouth or in suitable spawning substrate. Adults in 2007 either did not reach suitable spawning habitats or they spawned unusually late in the year (November-January) after my sampling had concluded, which would have greatly limited the period of time for juveniles to develop, emerge and grow before out-migrating (Carl 1982) to Lake Ontario. Interestingly, NYDEC was unable to procure the desired amount of

Chinook salmon eggs from migrating adults in the Salmon River, Pulaski, NY during the autumn of 2007 for hatchery rearing then stocking as fingerlings in Lake Ontario (The Syracuse Post Standard 2007, The Buffalo News 2007).

Chinook salmon—. I caught 44 adult Chinook in the fall of 2006, a majority 1 km downstream from the impassable barriers in the upstream reaches of both the east and west branches. Some Chinook reached the impassable barriers and attempted to breach the lower barrier in the West branch. None were successful at breaching the barrier and migrating upstream during direct observation. The habitat in these upstream reaches is the most suitable available for spawning salmonines; the substrate is primarily gravel, water temperature is low compared to the average for Sandy Creek, and flow is consistent and well oxygenated due to both reaches close proximity to waterfalls (also impassable barriers).

Coho salmon—. I caught only a few adult coho salmon in the fall of 2006. Those that were caught were staging for their upstream migration in the drowned river mouth of Sandy Creek, all within 1 km from the confluence with Lake Ontario. When pre-spawning coho salmon are triggered to migrate upstream they do so aggressively (Quinn 2005), and may travel 15 river km in 24 h, often at night. No adult coho were observed upstream of Route 19 or spawning.

Brown trout—. Adult brown trout were caught in large numbers in Sandy Creek during the autumn of 2006, during my sampling and by anglers interviewed for the NYDEC creel survey (Prindle and Bishop 2006). The overwhelming majority were caught by anglers at the creek mouth, although I caught 31 within 2 km of the confluence of the East and West branches of Sandy Creek. In this region, salmonine spawning habitat is unsuitable in the east branch and only fair in the west branch. The east branch is slow, turbid, warm, with silt substrate; the west branch has higher flow, lower temperatures, and mixed substrate. It is unlikely that brown trout were spawning in the east branch; they were likely migrating upstream when caught.

Rainbow trout/steelhead—. I caught 30 adult rainbow trout/steelhead during the winter and spring of 2007. They were caught throughout Sandy Creek and did not exhibit aggregation areas like those displayed by brown trout and Chinook salmon. The adults were observed over a four month period (February-May), demonstrating a longer stream residence prior to spawning than the other salmonine species. Fifteen adults were captured just downstream from the impassable fish barriers in each upstream branch in the most appropriate salmonine spawning habitat available to fishes in Sandy Creek. It is probable that others captured farther downstream had not completed their upstream spawning migrations.

Thirty-three adult rainbow trout/steelhead were unexpectedly captured in the West Branch of Sandy Creek in late August of 2007, tolerating temperatures at or exceeding their upper critical temperature threshold of 28 ^{o}C (Werner 1980, Quinn 2005). As water levels quickly dropped during the drought of 2007, these large adults lost the opportunity to out-migrate back to Lake Ontario and were stranded upstream after spawning in the spring. This provided an opportunity to study this species in an atypical temporal setting. Obvious post-spawning females and males persisted throughout the spring, summer, and autumn in good physical condition upstream in

Sandy Creek. This observation suggests that with watershed modification through land use practices aimed at moderating the flashiness of water temperatures, Sandy Creek has the potential to provide lifelong residence for rainbow trout/steelhead. Although extensively stocked throughout the Great Lakes, many wild rainbow trout/steelhead populations have become established (Rand et al. 1993). Specific watershed modifications to enhance the habitat of Sandy Creek and its watershed are discussed below in the "Management recommendations" section.

Emergence of alevins

Redds were assigned to species based on the temporal relationship between date of construction and peak adult upstream migration, as well as their dimensions; the latter was difficult due to overlapping and conflicting data on redd sizes constructed by each of the four salmonine species (Quinn 2005, Connor et al 2003, Alaska Dept. of Fish and Game 1999, USEPA 1999). The emergence traps deployed over five redds caught no salmonine alevins, although one was observed escaping when a trap was lifted. The most likely reason for not catching alevins (emerging yolk sac fry) in the spring of 2007 was installing the traps too late in a season during which warmer temperatures and a drought occurred (NOAA 2010, Weather Channel 2007). Four of the traps that were targeting Chinook salmon redds likely were installed after peak emergence of fry. The fifth trap targeted a redd, thought to be excavated by rainbow trout/steelhead due to their temporal differentiation in spawning compared to the other three species studied, probably was removed prematurely (rainbow trout/steelhead sac fry were caught within 100 m of this trap a month after removing it). Despite the failure of the emergence traps to capture emerging alevins, young salmonines were caught by backpack electrofishing and beach seines, yielding alevins, first and second year juveniles, and adults.

Sandy Creek iced over throughout its watershed during the winter of 2006-2007, although in many cases the creek flowed about 0.3 m below the ice, leaving an air-water interface. Pacific salmon eggs are viable under ice; when winter death occurs it has been attributed to desiccation, lack of oxygen, or disease (Brett 1956).

Juvenile salmonines

Chinook salmon—. Young of the year Chinook (N=46) were the most abundant and widely distributed salmonine in Sandy Creek during late winter and early spring (March to mid-May) of 2007 (Table 8). YOY Chinook grew rapidly during the spring of 2007 and disappeared before June. They appear to be adapted to thermal conditions in Sandy Creek by emigrating before their maximum thermal threshold of 24 ^{o}C (Quinn 2005, Werner 1980) is reached in early summer, a pattern which Carl (1982) substantiated in Lake Michigan. In their historical spawning areas in the Snake River drainage (Idaho, Washington), 98% of juvenile Chinook salmon start emigrating by the end of May and the smolt run is complete by the end of June (Connor et al. 2002). However, slow downstream movement and late summer passage associated with low flow levels can also result in exposure to temperatures over 20

^{o}C, prolonged exposure to which may disrupt Chinook growth, smoltification and downstream movement and exacerbate predation (Connor et al. 2003).

Coho salmon—. Young-of-year coho (N=29) were caught in high gradient spring fed headwater tributaries and roadside ditches in the Sandy Creek watershed. Water depth and current velocity may be more important parameters than substrate type in the habitat selection of sub-yearling coho salmon (Sheppard and Johnson 1985). The headwater habitat (site 46, Figure 1) was only 2 cm deep during the summer and fall of 2007, just enough to hold the juvenile coho. The roadside ditch quickly dried up in the late spring of 2007 and these juvenile coho were forced into a section of Sandy Creek unsuitable for their survival (warm, slow flow, turbid, bedrock substrate). Both sites harboring coho salmon contained little aquatic macrophyte cover. The scarcity of sub-yearling coho salmon, as well as rainbow trout/steelhead, in habitats with little aquatic macrophyte cover could reflect predator avoidance or predation pressure (Sheppard and Johnson 1985), or habitat preference.

Brown trout—. Few young-of-year brown trout (12) were caught in the spring and summer of 2007. Ice and snow make small streams such as Sandy Creek unsuitable for overwintering brown trout (Jonsson 1983), which may indicate why I captured so few, although Jonsson found a few overwintering parr between boulders and under ice along shore. Complex timber is a primary wintering habitat for brown trout in most low gradient rivers of north central North America (Kocik and Taylor 1996). Sandy Creek has few logjams to provide such habitat due to riparian agriculture; however, logjams potentially capable of harboring over-wintering brown trout were observed in stream segments of Sandy Creek with forested riparian zones. Brown trout were captured in logjams during my study, and Best Subsets Regression detected this relationship.

Rainbow trout/steelhead—. Juvenile rainbow trout/steelhead (N=51) tolerated high temperatures and low water levels in the highest numbers and at the most sites in 2007 (Table 8). Alevins were found over gravel-cobble substrates at depths of 0.1-0.3 m with mean velocities of 0.1-0.5 m/s, similar to the results of Sheppard and Johnson (1985). The highest density of rainbow trout/steelhead juveniles was in the east branch of Sandy Creek upstream from the Erie Canal, a region with lower water temperatures than downstream reaches (Tables 10 and 12). This finding was consistent with Ebersole et al. (2001) who noted that some rainbow trout/steelhead used thermal refugia 3-8 ^{o}C colder on average than ambient stream temperatures. However, Sandy Creek provides limited suitable habitat for juvenile salmonines in dry years such as 2007. Ebersole et al. (2001) showed for arid streams (less than 5 cm of precipitation per month) in Oregon, comparable to Sandy Creek in 2007, that with prolonged high water temperatures thermal refugia in Sandy Creek may be too small and sporadic to sustain high densities of rainbow trout/steelhead.

Two, 2-year old rainbow trout/steelhead (212 and 222 mm total length) were captured in 2007; all of the other salmonine juveniles caught were young-of-year. The two larger juveniles did not have marks from stocking, indicating that they were either wild spawned fish that maintained residency in Sandy Creek or fish stocked by the annual NYDEC pen rearing project in lower Sandy Creek. Pen reared fish are preferably stocked ~1 km offshore in Lake Ontario, after imprinting on Sandy Creek, to reduce post release predation. If water temperatures rise rapidly and exceed ideal temperatures, pen reared fish are released immediately at the mouth of Sandy Creek. Two or more fish could have migrated upstream as young of year if prematurely released from the pen rearing project and established residency upstream where captured. If these fish survive they will imprint on Sandy Creek when smolting and out-migrating to Lake Ontario and return as adults to spawn.

Growth—. Juveniles grew from 20-100 mm as spring water temperatures gradually increased from 4-18 °C. In June 2007, as water temperatures rapidly rose from 18 °C to the mid- and upper 20 °C-range, fingerling growth stopped, consistent with laboratory studies where juveniles refused to eat and respiration rates rose greatly (Brett 1956, Connor et al. 2002). Temperatures fluctuated throughout the summer, but once they fell below 22 °C in late summer and fall of 2007 there were slight increases in size. The largest young of year salmonines caught were Chinook, which grew rapidly from emergence to apparent out-migration in June, and rainbow trout/steelhead that remained in Sandy Creek during the entire study period. Optimal temperature for Pacific salmon growth and food utilization is approximately 10-18 °C (Connor et al. 2002). Temperature acts as a controlling factor; it constantly conditions the fish through acclimation while governing the scope for metabolic rate. Performance is best in the region of the preferred temperature, while sensitivity to small gradients of temperature may act as a directive factor (Brett 1956).

Ecology—. The potential for competition may limit the numbers of juvenile brown trout in Sandy Creek. Of the four salmonine species studied, brown trout (Atlantic drainages) and rainbow trout/steelhead (Pacific drainages) are most likely to interact strongly as juveniles in Sandy Creek because these species did not co-evolve. Both rainbow trout/steelhead and brown trout spawn later than Chinook and coho salmon and both use pool habitats as juveniles (Fausch and White 1986). In their native and introduced ranges, the habitat requirements of brown trout and rainbow trout/steelhead are similar for juveniles, although temporal and spatial partitioning probably minimizes interactions between species (Kocik and Taylor 1996). Laboratory studies indicate that juvenile coho salmon (the most similar Pacific salmonine to rainbow trout/steelhead) out compete brown trout of similar size and that coho held positions significantly farther upstream than brown trout (Fausch and White 1986). In my study, Sandy Creek's headwaters held coho salmon while brown trout occupied reaches further downstream.

In some tributaries of Lake Ontario, natural reproduction of both coho salmon and rainbow trout/steelhead is common (Sheppard and Johnson 1985). Sandy Creek is utilized for spawning by adults of both species, and juveniles survive, in years when creek conditions permit.

Salmonine production potential in Sandy Creek

Sandy Creek is classified as a warmwater stream by NYDEC. Based on the CPUE data in Table 8, it may produce 6,905 juvenile salmonines per creek-ha per year (2,302 Chinook, 1,451 coho, 2,552 rainbow trout/steelhead, 600 brown trout). The Salmon River, tributary to eastern Lake Ontario, is classified as a river capable of holding trout and salmon by NYDEC and is estimated to produce 5.2 million juvenile Chinook salmon annually; although it is unknown how many survive to adulthood (Everitt 2006). Clearly, Sandy Creek is not a major contributor to salmonine production in the Lake Ontario watershed. On average over 14 years, 1992 to 2005, the annual proportion of wild age-3 Chinook salmon recruited to the Lake Ontario population from American and Canadian tributaries was 62% (±13.6%, 95% CI) of the population, but has varied between 24% (±9.4%) and 82% (±11.2%) (Connerton et al 2009).

<u>Weather</u>—.The weather dictated the success and failure of salmonine reproduction and emergence in 2006 and 2007, respectively, in Sandy Creek. The autumn of 2006 had above average rainfall (NOAA 2010, Weather Channel 2007, USGS 2010) which filled Sandy Creek and permitted adult migration upstream to the best available spawning habitats. In 2007 western New York experienced its worst drought since 1960 (Weather Channel 2007), Sandy Creek did not fill its basin, and some regions were dewatered during late July and August. Creek temperatures reached 28^{o} C (Table 10). High water temperatures and lack of cover made juvenile salmonines susceptible to predation through an absence of deep water and bank cover and decreased vigor for escape. Great Blue Heron and Belted Kingfisher were the main predators of juvenile salmonines observed in Sandy Creek.

Fish community of Sandy Creek

The by-catch fish community consisted of three distinct aggregations based on habitat type. In the drowned river mouth, walleye, northern pike, longnose gar and bowfin were the large predators; emerald shiner, brook silverside, golden shiner and alewife were common pelagic species; and brown bullhead, common carp, white sucker and redhorse suckers (*Moxostoma* spp.) inhabited the benthos. The mid-river reaches between the mouth and headwaters were inhabited by a warmwater community. Smallmouth and largemouth bass, rock bass and yellow perch comprised the predatory component of this section. Many sunfishes (bluegill, green sunfish, pumpkinseed, black crappie), shiners (striped, spotfin), chubs (river, hornyhead), darters (fantail, johnny), stonecats, banded killifish, central mudminnow and northern hog sucker also occupied this segment. The reaches of Sandy Creek upstream of the Erie Canal were higher gradient segments harboring headwater species, including blacknose and longnose dace, creek chub, common stoneroller, rainbow darter and salmonines. Latin names for these species are in Table 4.

Two fishes caught during my sampling were unexpected, because their published range does not encompass Sandy Creek or because of their rarity in the Great Lakes region (Smith 1985, Carlson and Daniels 2004). The river chub (*Nocomis micropogon*) was abundant in the middle reaches of the main stem of the Sandy Creek (Table 5). Some field guides place this species' known region of occupation outside the Sandy Creek watershed (Page and Burr 1991, Smith 1985). Two, meter-long female American eels (*Anguilla rostrata*) were caught by boat electrofishing in the drowned river mouth near Sandy Creek's confluence with Lake Ontario (Table 5). The once abundant American eel is becoming extremely rare in the Great lakes region and nearing extirpation (personal communication, Dawn Dittman USGS, Cortland, NY).

The secondary invasion of round goby (*Apollonia melanostoma*) from the Erie Canal into the upper regions of Great Lakes tributaries like Sandy Creek may have ecological impacts on the native fish and mussel community through competition and predation. Round gobies typically out-compete native benthivorous fishes such as logperch (*Percina caprodes*) and mottled sculpin (*Cottus bairdii*), and similar consequences can be expected for other small benthic species (Poos et al. 2009). Gobies also may have direct impacts through predation on juvenile fish and fish eggs (Poos et al. 2009). The Erie Canal vector placed the round goby within 1 km of the most productive salmonine spawning and nursery habitat in Sandy Creek (Figure 17, Table 5). Round goby competition with or predation on obligate host fishes of unionid mussel glochidia are an impending impact on Sandy Creek's unionid mussel community (Poos et al. 2009).

Conclusions

The ability of adults to access areas of the watershed suitable for reproduction—. Adults of the four species studied access the best salmonine spawning habitats in years with average or greater precipitation. These spawning grounds are upstream (south) of Route 104, and large migratory fishes require a half meter of water depth at bottlenecks to successfully navigate to these reaches in Sandy Creek. In the fall of 2007 only one small male Chinook salmon was captured in the optimal spawning grounds of the creek. The Sandy Creek watershed experienced the driest year since 1960 in 2007.

The impassable barrier in the east branch is a relic of the waterfall that led to the excavation of the glen that extends from the canal spillway to Sandy Creek which has since receded ~2 km south to the creek crossing at South Holley Road, where a low-head hydroelectric dam operates (Figure 1). The removal or remediation for fish passage of the dam in the east branch would make available an additional 3 km or 20% more spawning and juvenile habitat than currently exists in the east branch.

The first impassable barrier reached by migrating fishes in the west branch, a vertical ledge and culvert with very shallow water located beneath the Brown Street Bridge in Albion (Figure 1), is 80 m upstream (south) from the canal diversion into Sandy Creek. Removal or remediation for fish passage of the impassable barrier in the west branch would provide 10% more suitable habitat for salmonines. However, such removal would have to be accompanied by the mitigation of ~1 km of natural migration barriers, a series of three bedrock shelves averaging 0.5 m in height, starting 100 m upstream from the impassable culvert.

<u>Extent and suitability of substrates for redd construction and larval development</u>—. Salmonine spawning habitat in Sandy Creek is limited due to the lack of suitable spawning substrate. Route 104 (Ridge Road) marks the maximum boundary of the post-glacial, southern Lake Ontario (Lake Iroquois) shoreline. North

of this border the creek's substrate is primarily bedrock. Gravel that has accrued in this region due to water flow, ice, and erosion are composed of particles too large and sparsely aggregated to support salmonine spawning (Quinn 2005). The west branch of the creek has the best substrate for spawning, from the confluence with the east branch to the impassable barrier in the Village of Albion. There are large (50 m x 10 m) gravel beds in this section, and many adult fish and redds were observed. The other suitable spawning habitat in Sandy Creek is a small region in the east branch south of the Erie Canal in the Village of Holley. This section has gravel substrate and is within 1 km of the consistent, cold tributaries that support juvenile coho salmon.

<u>The extent and suitability of habitat conditions</u>—. Habitat conditions needed by juveniles before migrating to Lake Ontario vary by species based on life history traits. Chinook salmon were the most evenly distributed juvenile salmonine captured. They are able to utilize all of Sandy Creek as juveniles and apparently emigrate to Lake Ontario in June before creek temperatures become lethal.

Juvenile coho were found only in limited, small scale habitats with consistently cold, flowing water. They held residence in the tributaries of the east branch through the summer and fall seasons due to thermal requirements. Other sites containing juvenile coho were roadside ditches that dried up in late June 2007, forcing them into lethal water temperatures in the Erie Canal-fed creek.

Juvenile rainbow trout/steelhead can survive in both upstream branches of Sandy Creek through the summer season. They are tolerant of higher temperatures than the other Pacific salmonine species and utilize varied microhabitats to stay within their thermal range. They were caught in forested riparian areas, agricultural irrigation holes, and gravel riffles, runs, and pools. The greatest density of juveniles was in the small region of the east branch south of the Erie Canal in the Village of Holley. Fish in this section experienced cooler water temperatures, closest to their optimal water temperature, due to tributary influences and the lack of canal influence.

Juvenile brown trout were caught in low numbers, often sheltered by instream wood. Although many adult brown trout were caught during the spawning migration, it is curious as to why more juveniles were not caught in this study, especially since brown trout have high temperature tolerances among salmonines. Professional agencies (NYDEC, USGS) have found similar results, but early mortality syndrome is not the cause (pers. comm., George Ketola, USGS, Cortland, NY).

Future research

<u>Monitor salmonine emigration</u>—. It is important to account for wild spawned recruits to Lake Ontario's salmonine population in order to limit the potential for non-native, stocked salmonines to out-compete native, resurgent Atlantic salmon and lake trout populations for prey or spawning sites, and to avoid excessive predation on the juveniles of native salmonines (Carl 1982). Sandy Creek may contribute thousands of YOY wild-spawned Chinook salmon to Lake Ontario in springs following autumns with average or better rainfall. Twenty-four hour sampling should be conducted starting in May to assess emigration of Chinook and other salmonines.

Estimate alevin emergence—. To provide an estimate of the number of emerging yolk-sac fry from each redd by species, fry emergence traps should be deployed just after ice out in the spring or in the final week of February after a mild winter without ice. This will ensure that the traps are in place for peak emergence and that they aren't distorted or transported by ice flow, thereby disturbing or destroying the redd and eggs beneath.

Management recommendations

Preserve existing cold water habitat—. One 2-km section of Sandy Creek's east branch supported more juvenile salmonines than any other part of the creek. The forested riparian zone of this unique section should be protected from future development to preserve salmonine habitat and protect it from sediment run off and high stream temperatures. A 3 °C increase in summer water temperature would fragment or eliminate this cold water fish habitat. This area is critically important for trout and salmon production in Sandy Creek.

Re-establish a riparian buffer—. The establishment of a consistent, forested riparian buffer along Sandy Creek would positively impact water quality and the entire fish community. Cultivating land or building impervious surfaces exposes soil to erosive forces which move sediments, nutrients and pollutants to waterways. Re-establishing riparian corridors, ideally with native vegetation, 20-100 m wide, depending on land gradient, and using best management practices (BMPs) in agriculture and construction, would greatly reduce or eliminate damage to the water quality and the fish community of Sandy Creek. A maximum summer water temperature below 22 °C was the critical factor distinguishing trout from non trout streams in Ontario, Canada (Keleher and Rahel 1996). The temperatures in Sandy Creek during the summer of 2007 reached 28 °C and 90% of stream reaches experienced temperatures above 22 °C.

Establish a watershed association—. The best way to achieve the recommendations above is to establish a Sandy Creek Watershed Association to advocate for the ecological health of the creek and its surrounding terrestrial areas. Watershed and water body conservation organizations are vital to protect public resources from degradation by anthropogenic activity. These groups focus the attention of many stakeholders on a common goal. This gives the organizations power through the congregation of different talents and pooled resources (pers. comm., Dr. James Zollweg, The College at Brockport, SUNY). Diverse groups use Sandy Creek and its watershed for recreation, living and livelihoods, and the community receives economic support from these uses. Anglers from New York and many other states fish Sandy Creek during the adult salmonine upstream migration in the fall and they fish Lake Ontario during the spring and summer (Prindle and Bishop 2006), all while purchasing bait, guide and charter services, tackle, fuel, food, and lodging from local vendors. Recreational power and sail boaters have access to a free NYDEC boat launch at the mouth of the creek. Sandy Creek provides safe harbor from and connectivity to Lake Ontario, thus harboring many recreational and professional boats and sheltering Great Lakes travelers from storms. Mammal and bird hunters and bird watchers enjoy their pursuits in the Sandy Creek watershed. The cooperation of these user groups toward the conservation of the Sandy Creek watershed and the biological and economic resources it provides would help preserve its ecology, water quality, and trout and salmon production.

The Erie Canal conundrum—. The Erie Canal presents a conundrum concerning Sandy Creek's warmwater and salmonine fish communities. The canal is beneficial to the warmwater community by providing consistent base flows during spring, summer and autumn for Sandy Creek's fishes living downstream of the canal discharges in the east and west branches. This base flow also supports young-of-year rainbow trout/steelhead survival in the summer, but the warm temperatures are problematic. Under low flow conditions, anadromous species that reside in tributary streams the longest (rainbow trout/steelhead in Sandy Creek) are impacted the most (Sheppard and Johnson 1985).

Water temperature and dissolved oxygen levels are not stratified by depth in the Erie Canal (Table 12). Sluice gates are installed at an average depth of 3 m and cannot be lowered, even if there was a stratified deeper water layer of cooler temperature with which to feed Sandy Creek. The water temperature of the canal is considerably warmer than that from Sandy Creek upstream of the canal influence (Tables 10, 12), and higher than juvenile salmonines can tolerate. In years of drought and low natural creek flow, as occurred in 2007, there is little water from the headwaters of Sandy Creek to moderate the high temperatures of incoming canal water. This prevents habitat downstream of the canal influences from harboring juvenile salmonines over one or two summers, as is required for rainbow trout/steelhead and coho salmon, respectively. The area potentially affected is 99% of the spawning habitat accessible to adults (Figures 11, 13).

Survival of sub-yearling Chinook salmon during seaward migration is directly proportional to flow (Connor et al. 2003); therefore, the restoration of base flow in spring that is shut down in winter after the canal is drawn down (November-April) probably stimulates emigration of Chinook smolts in May. Juvenile Chinook salmon that migrate downstream when flow is low and temperatures are warm suffer high mortality because they are exposed longer to actively feeding predators in clear water (Connor et al. 2003).

Canal flow in the fall undoubtedly assists upstream migration of adults to potentially good spawning areas in the middle (Chinook) and upper (rainbow trout/steelhead) watershed. More water in the creek requires adults to expend less energy swimming upstream; they can swim through runs of moderate depth rather than negotiating long, shallow riffles and jumping over small barriers. Conserving energy during migration retains adult fitness for female redd building and male competition for females. Higher bank stage also provides cover for migrating adults from predators. The large fish are not exposed to raccoons, mink, and fish eating raptors as much in high water as they are in low water conditions.

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Tables

Table 1. Substrate classification and measurement system. Substrate score was calculated by assigning a number to a category based on importance to salmonine ecology (Quinn, 2005) Fines-silt 1, Sand 2, Gravel 6, Cobble 5, Boulder 2, Bedrock 1, Detritus 1) and calculating a weighted average based on the percentage of each substrate type in a transect (e.g., a transect composed of 40% cobble and 60% gravel was assigned a substrate score of 5.6).

Category	**Diameter of Particle (mm)**
Fines	<1mm
Sand	1-5mm
Gravel	5-80mm
Cobble	80-300mm
Boulder	>300mm
Bedrock	-
Detritus	-

Table 2: Percent riparian and canopy cover at sampled sites. Riparian cover estimates the uninterrupted distance of canopy cover from the stream bank inland. HSI = Habitat Suitability Index = depth of the riparian zone x percent canopy cover, scale 0-100.

			Depth and Land Use of the Riparian Zone				
			Right bank		Left bank		
Site	Date	% Canopy	Depth (m)	Type	Depth (m)	Type	HSI
	Intentionally selected sites						
145	9/21/2006	5	5	Res	5	Res	0.5
76	7/7/2006	2	0	Farm	30	Forest	0.6
81	7/11/2006	5	0	Res	20	Farm	1
86	7/19/2006	5	3	Farm	20	Y. Forest	1.15
80	7/7/2006	5	15	Farm	15	Farm	1.5
143	9/21/2006	10	20	Res	20	Res	4
152	9/21/2006	10	10	Forest	50	Forest	6
149	9/21/2006	30	1	Res	20	Y. Forest	6.3
135	9/9/2006	30	1	Res	30	Forest	9.3
70	6/23/2006	60	10	Forest	10	Forest	12
121	9/9/2006	35	20	Farm	20	Farm	14
104	7/21/2006	30	20	Shrub	30	Forest	15
147	9/21/2006	25	10	Forest	50	Forest	15
148	9/21/2006	25	10	Forest	50	Forest	15
127	9/9/2006	35	15	Field	30	Field	15.75
129	9/9/2006	50	20	Farm	40	Forest	30
134	9/9/2006	50	20	Field	50	Forest	35

120	8/1/2006	60	30	Forest	30	Forest	36
90	7/19/2006	80	30	Y. Forest	30	Y. Forest	48
119	8/1/2006	80	30	Forest	30	Forest	48
68	6/23/2006	70	50	Forest	50	Forest	70
	Randomly selected sites						
102	7/21/2006	50	0	Farm, Res	0	Farm, Res	0
98	7/20/2006	5	20	Forest	0	Roads	1
105	7/26/2006	40	0	Res	5	Farm	2
131	9/9/2006	5	10	Farm	30	Forest	2
111	7/26/2006	20	5	Res	10	Rt. 104	3
75	6/26/2006	5	20	Forest	50	Forest	3.5
78	7/7/2006	10	20	Forest	20	Forest	4
107	7/26/2006	80	0	Res	10	Farm	8
95	7/20/2006	30	0	Res	30	Forest	9
85	7/11/2006	30	10	Farm	25	Y. Forest	10.5
74	6/26/2006	20	30	Shrub	30	Shrub	12
140	9/18/2006	60	10	Y. Forest	10	Y. Forest	12
114	7/26/2006	30	1	Farm	40	Forest	12.3
142	9/21/2006	25	25	Y. Forest	25	Y. Forest	12.5
83	7/11/2006	20	15	Y. Forest	50	Y. Forest	13
125	9/9/2006	20	30	Forest	50	Forest	16
137	9/18/2006	80	10	Farm	10	Farm	16
92	7/19/2006	30	30	Y. Forest	30	Y. Forest	18
109	7/26/2006	40	10	Farm	50	Field	24
117	8/1/2006	40	20	Res	40	Forest	24

Table 3: Potential sediment runoff impact after a moderate rainstorm at sites on Sandy Creek. Sites identified by orthoimagery (NYSGIS Clearinghouse): blank = minimal, x = minor, xx = major.

Longitude	Latitude	Degree Impact	Comments	Branch
-77.903	43.3437		Near mouth	Main
-77.9105	43.3419		Near mouth	Main
-77.9209	43.3356			Main
-77.9334	43.3352	X		Main
-77.9401	43.3253			Main
-77.9442	43.3155	Xx		Main
-77.9521	43.3153			Main
-77.9726	43.2936			Main
-78.0106	43.2953	X		Main
-78.0253	43.2925		Cow farm	Main
-78.0697	43.2712	Xx	Erosion to creek observed	West
-78.0742	43.2683		Same cow farm as above	West
-78.0984	43.2615			West
-78.112	43.2629			West
-78.1294	43.2608		Narrow riparian zone upstream 0.5 mi.	West
-78.1495	43.2556	Xx	Cultivated to one stream edge	West
-78.1654	43.2538	Xx	Cultivated to one stream edge, WWTP	West
-78.1834	43.2474		Erie Canal input at Albion	West
-78.1829	43.2467		Road culvert impassable to fish	West

-78.1734	43.2374	X	Cultivated to one stream edge	West
-78.1548	43.2343	X	Cultivated to one stream edge	West
-78.1804	43.2313	X	Cultivated to one stream edge, nearing headwaters	West
-78.1814	43.2166	X	Cultivated to one stream edge, nearing headwaters	West
-78.206	43.2128	X	Headwaters in a cultivated field	West
-78.0345	43.2669		Tributary through cultivated field	East
-77.9984	43.254			East
-77.9889	43.2471			East
-77.9883	43.2442		Cultivated to one stream edge, erosion observed	East
-77.9943	43.2425	X	Split channel through cultivated field	East
-78.0179	43.2258		Erie Canal input at Holley	East
-78.0277	43.2118		Dam impassable to fish	East
-78.061	43.1837			East
-78.0652	43.1751			East
-78.0437	43.1631		Cultivated to both stream edges	East
-78.0442	43.1791	Xx	Many eroded gullies from farms	East
-78.026	43.1931			East
-77.9878	43.1968		Headwaters in a cultivated field	East

Table 4: Common and scientific names of fishes caught and the codes used to represent them in tables and figures.

Common Name	Scientific Name	Code
Longnose gar	*Lepisosteus osseus*	Le os
Bowfin	*Amia calva*	Am ca
White sucker	*Catostomus commersoni*	Ca co
Northern hog sucker	*Hypentelium nigricans*	Hy ni
Shorthead redhorse	*Moxostoma m. macrolepidotum*	Mo ma ma
Golden redhorse	*Moxostoma erythrurum*	Mo er
Greater redhorse	*Moxostoma valenciennesi*	Mo va
Chinook salmon	*Oncorhynchus tshawytscha*	On ts
Coho salmon	*Oncorhynchus kisutch*	On ki
Rainbow trout	*Oncorhynchus mykiss*	On my
Brown trout	*Salmo trutta*	Sa tr
Stonecat	*Noturus flavus*	No fl
Brindled madtom	*Noturus miurus*	No mi
Brown bullhead	*Ameiurus nebulosus*	Ic ne
Margined madtom	*Noturus insignis*	No in
Striped shiner	*Notropis chrysocephalus*	No ch
Spotfin shiner	*Notropis spilopterus*	No sp
Sand shiner	*Notropis stramineus*	No st

Emerald shiner	*Notropis atherinoides*	No at
Golden shiner	*Notemigonus crysoleucas crysoleucas*	No cr cr
Bluntnose minnow	*Pimephales notatus*	Pi no
Fathead minnow	*Pimephales promelas*	Pi pr
Central mudminnow	*Umbra limi*	Um li
Creek chub	*Semotilus atromaculatus*	Se at
Hornyhead chub	*Nocomis biguttatus*	No bi
River chub	*Nocomis micropogon*	No mi
Eastern blacknose dace	*Rhinichthys atratulus*	Rh at
Longnose dace	*Rhinichthys cataractae*	Rh ca
Alewife	*Alosa pseudoharengus*	Al ps
Banded killifish	*Fundulus diaphanous*	Fu di
Troutperch	*Percopsis omiscomaycus*	Pe om
Brook silverside	*Labidesthes sicculus*	La si
Round goby	*Apollonia melanostoma*	Ap me
Central stoneroller	*Campostoma anomalum*	Ca an
Common carp	*Cyprinus carpio*	Cy ca
Grass pickerel	*Esox americanus vermiculatus*	Es am ve
Northern pike	*Esox lucius*	Es lu
Rock bass	*Ambloplites rupestris*	Am ru
Green sunfish	*Lepomis cyanellus*	Le cy
Bluegill	*Lepomis macrochirus*	Le ma

Pumpkinseed	*Lepomis gibbosus*	Le gi
Largemouth bass	*Micropterus salmoides*	Mi sa
Smallmouth bass	*Micropterus dolomieu*	Mi do
Black crappie	*Pomoxis nigromaculatus*	Po ni
Yellow perch	*Perca flavescens*	Pe fl
Walleye	*Sander vitreum*	Sa vi
Logperch	*Percina caprodes*	Pe ca
Rainbow darter	*Etheostoma caeruleum*	Et ca
Fantail darter	*Etheostoma flabellare*	Et fl
Johnny darter	*Etheostoma nigrum*	Et ni
Banded darter	*Etheostoma zonale*	Et zo

Table 5: Salmonine redd presence and fishes caught by site in Sandy Creek. Salmonines (bold) are adult catches. NS indicates that a site was not sampled for redd presence.

Site	GPS Coordinates	Fall 2006 Redds	Species Caught
	Intentionally selected sites		
68	N43.13.095, W078.01.544, 174m	8	**4 On ts, 2 On my, 4 Sa tr**, Se at, Rh at, Ca an, Pi no, Et ca, Am ru
70	N43.12.722, W078.01.564, 157m	2	**4 On my,** Hy ni, Ca co, Le gi, Am ru, Se at, Pi no, Et ca, Rh ca
76	N43.20.277, W077.55.088, 86m	0	**3 Sa tr**, Am ru, Fu di, Um li, No ch, Le gi, Mi do, Mi sa, No bi, Pi no, Cy ca, No in, No fl, Pe fl
80	N43.20.165 W077.55.573 81m	4	**4 Sa tr**, Am ru, Fu di, No ch, Et ca, Et fl, Le ma, Le gi, Um li, No at, Le cy, No bi, No fl, Pi no, Mi do
81	N43.20.277 W077.55.088 86m	5	**2 On ts**, No in, Le gi, Le ma, No ch, No bi, No fl, Fu di, Am ru, Et fl, Mi sa, Hy ni, Pe fl
86	N43.18.986 W077.56.616 108m	0	**2 On my, 1 Sa tr**, No ch, Am ru, No bi, Pi pr, Pi no, Et fl, Et ca, Le gi, No cr, Cy ca

90	N43.18.310 W077.57.316 95m	6	**4 On my, 3 Sa tr**, Am ru, Et ca, Et fl, Pi no, No bi, Le gi, Ic ne, Se at, Hy ni, Um li, Am ru, No ch
104	N43.16.921 W078.02.673 112m	NS	4 On ki, Am ru, Le gi, No ch, No bi, Ca co, Mi do, Mi sa, Pi no, Et fl, Et ca
119	N43.13.628 W078.01.026 184m	4	**6 On ts, 4 Sa tr**, Mo va, Mo ma ma, Mo er, Hy ni, Pi pr, Pe om, Pe ca, Le cy, Le gi, Am ru, No ch, No bi, Se at, Ap me, Pi no, Et ca, Et ni, No fl, No at, Cy ca, Le ma
120	N43.13.994 W078.00.773 130m	NS	Ap me, A,m ru, Pe ca, Et ca, Et ni, No ch, No bi, Se at, Pi no, Hy ni, Ca co, Mo er
121	N43.15.815 W078.06.295 199m	3	**6 On my, 4 Sa tr**, Ca co, No fl, No ch, Ca an, Se at, Hy ni, Pi no, Et ca, Pi pr, Le cy, Am ru
127	N43.15.832 W078.05.224 164m	NS	Cy ca, No bi, Se at, Ca an, Hy ni, No ch, Et ca, Et fl, Am ru, Mi do
129	N43.16.005 W078.04.861 129m	NS	No bi, Se at, Et ca, Et fl, Et ni, Pi no, Ca co, Ca an, No ch, Hy ni, Rh ca, Cy ca
134	N43.16.330 W078.04.070 103m	2	**3 On ts**, Et ca, Et fl, Mi do, No ch, No bi, Se at, Ca an, Pi no

135	N43.16.400 W078.03.881 165m	NS	Le gi, Hy ni, Mi do, No ch, Et ca, Et fl, Ca an, No bi, Pi no, Ca co
143	N43.14.712 W078.10.886 212m	4	**3 On ts**, Se at, Pi no, Et ni, No ch, Hy ni, Mi sa, Le gi
145	N43.14.810 W078.10.987 160m	0	**4 On ts**, Le gi, No ch, Se at, Pi no, No sp, No fl, Mi sa, Ca an, Am ru, Pi pr
147	N43.14.938 W078.11.048 152m	1	**2 On ts**, No bi, Se at, Et ca, Et fl, Et ni, Ca an, No fl, Ap me, Am ru, No mi, Le ma, Le gi, No ch, No at, Pi no, Um li
148	N43.14.981 W078.10.992 180m	1	**4 On ts**
149	N43.14.976 W078.10.890 195m	2	**2 On ts**, Se at, No bi, Am ru, Ca an, Rh at, Pi no, No in, No fl, Um li, Et ca, Et ni, Et fl, No mi, Ca co
152	N43.15.220 W078.10.230 172m	2	**4 On ts**, Et ca, Et ni, Et fl, Pi no, Pi pr, No bi, Se at, Um li, Ca an, No fl, Ap me, Am ru, Pi pr, No at, Ca co
	Randomly selected sites		
74	N43.20.542 W077.54.269 83m	0	Le os, Ic ne, Ca co, Mo va, Am ca, No at, Am ru, Pe fl, Al ps, Mi sa, Le gi, Le ma, No st, Pi pr, Cy ca, Po ni, La si, No cr, Es lu, Sa vi

75	N43.20.488 W077.54.674 77m	0	Pe fl, Et ca, Le cy, Le gi, Le ma, Am ru, Mi do, Cy ca, Mi sa, Pi no, No bi, No ch, No fl, Ic ne, Fu di, Hy ni, Ca co, Ca an
78	N43.20.145 W077.55.216 81m	2	No fl, Et ca, Et fl, Pe fl, Am ru, Le gi, Le ma, Mi sa, Mi do, No bi, Pi no, Cy ca, No ch, Le os, Hy ni, Fu di
83	N43.20.145 W077.55.216 81m	1	No ch, Pi no, No bi, Hy ni, Mi do, Mi sa, Pe fl, Am ru, Cy ca, Le gi, Fu di, Et ni, Et ca, Et fl, Pi pr, No fl
85	N43.20.165 W077.55.573 81m	0	**1 Sa tr**, No fl, Am ru, Es lu, No ch, Pi no, Cy ca, No bi, Le gi, Mi sa, Mi do, Et ni, Um li, Et ca, Et fl
92	N43.17.688 W077.58.537 93m	0	Am ru, Le cy, No bi, Um li, Fu di, Et ni, Et ca, Et fl, Et zo, No fl, No ch, Cy ca, Hy ni, Mi do, Pe fl, Se at, Ca an, Ca co, Pi no, Rh at, Pe om
95	N43.17.279 W078.02.213 108m	0	**4 Sa tr**, No bi, Et ca, Et fl, Le cy, Am ru, Mi do, Se at, Pi no, Pi pr, No ch, Hy ni, Ca co, Ca an

98	N43.17.549 W078.01.367 117m	0	Am ru, Hy ni, Um li, Pi no, Cy ca, No mi, No bi
102	N43.16.076 W078.02.118 114m	NS	Am ru, Le gi, No ch, No bi, Ca co, Mi do, Mi sa, Pi no, Et fl, Et ca
105	N43.14.560 W077.59.625 143m	NS	Ca an, No bi, Se at, No ch, Am ru, Hy ni, Ca co
107	N43.14.922 W077.59.216 109m	NS	Ca an, No bi, Se at, No ch, Am ru, Hy ni, Ca co
109	N43.15.222 W077.59.936 162m	NS	Mi do, Mi sa, Mo er, Hy ni, Et ni, No cr cr, No at, Pi no, Am ru, Le cy, No sp, Cy ca
111	N43.15.360 W078.00.269 197m	NS	Cy ca, No bi, Pi no, Am ru, Et ni, Et zo, No ch, No sp, Hy ni
114	N43.15.564 W078.01.285 138m	NS	Le cy, Et ni, Et fl, No sp, No st, Ap me, Pi no
117	N43.13.450 W078.01.219 131m	NS	Mo ma ma, Ca co, Mi do, Am ru, Le gi, Ap me, Mo er, Le cy, Es am ve, Pi no, Se at, Et ca, Et ni
125	N43.15.784 W078.05.735 158m	NS	No bi, Se at, Pi no, Pi pr, Et ca, Et fl, Et ni, Ca an, No fl, Rh ca, Ca co, Hy ni, No ch
131	N43.16.161 W078.04.416 170m	3	**4 On ts**, Mi sa, Mi do, Ca co, Et ca, Et fl, Et ni, Pi no, No ch, No bi, Se at, No fl, Ca an, Hy ni, Mo er

137	N43.15.269 W078.09.385 254m	5	**4 On my, 2 Sa tr**, Cy ca, Am ru, Ic ne, No in, No bi, Pi no
140	N43.15.841 W078.06.547 155m	1	**6 On my**, Hy ni, Pi no, Se at, No bi, Ca an, No ch, Et ca, Le cy, Et zo
142	N43.14.630 W078.10.833 183m	0	Se at, Pi no, No ch, Hy ni, Et ni
	Additional sites		
168	N43.17.708 W077.57.964 115m	NS	**2 On my, 1 Sa tr**, Ca co, Hy ni, No bi, No ch, Am ru, Ca an
173	N43.15.537 W078.07.086 168m	1	**3 On ts**

Table 6: Land use designation and percentages occurring within Sandy Creek's watershed. Count is the number of 30m x 30m cells occupied by each land use type in the Sandy Creek watershed. Source: USGS 30-m resolution land cover dataset, northeast US region, https://usgs.gov.

Code	Land Use	Count	Percent of Watershed
11	Open Water	2108	0.53
21	Developed Open Space	22048	5.50
22	Developed Low Intensity	7570	1.89
23	Developed Medium Intensity	1129	0.28
24	Developed High Intensity	244	0.06
31	Barren Land (rock,silt,clay)	75	0.02
41	Deciduous Forest	83773	20.88
42	Evergreen Forest	871	0.22
43	Mixed Forest	9412	2.35
52	Shrub/scrub	6316	1.57
71	Grassland, Herbaceous	1009	0.25
81	Pasture/Hay	102850	25.64
82	Cultivated Crops	128403	32.01
90	Woody Wetlands	33963	8.47
95	Emergent Herbaceous Wetland	1358	0.34
	Total	401129	100

Table 7: Adult salmonine numbers for Sandy Creek: this study, NYDEC creel survey, and NYDEC stocking.

Species	This study 2006	Percent of sample	Creel survey 2006	Percent of sample	Stocking 2002-04	Percent of sample
Chinook	44	40.74%	1525	20.44%	129370	52.01%
Coho	3	2.78%	36	0.48%	26000	10.45%
Rainbow	30	27.78%	727	9.74%	35550	14.29%
Brown	31	28.70%	5174	69.34%	57820	23.25%
Totals	108		7462		248740	

Table 8: Catch per unit effort data for juvenile salmonines represented in raw catch data and fish per acre. On ts – Chinook salmon, On ki – Coho salmon, On my – Rainbow trout, Sa tr – Brown trout. Heading numbers 1-4 are numbers assigned to each salmonine species used in the equation for generating salmonine score ((species number x number caught) / total salmonines caught)).

Site	Salmonine Score	YOY Salmonines				Fish Per Hectare				
		On ts 1	*On ki 2*	*On my 3*	*Sa tr 4*	*On ts*	*On ki*	*On mi*	*Sa tr*	*All species*
	Intentionally selected sites									
68	1.0	1	0	0	0	50	0	0	0	50
	2.3	11	3	20	0	550	150	1001	0	1701
	2.5	0	5	6	0	0	250	300	0	550
	3.0	0	0	3	0	0	0	150	0	150
	2.7	0	2	0	1	0	100	0	50	150
70	2.1	5	4	6	0	250	200	300	0	751
	3.7	0	0	3	7	0	0	150	350	500
	2.4	0	5	1	1	0	250	50	50	350
	3.0	0	0	1	0	0	0	50	0	50
	3.0	0	0	1	0	0	0	50	0	50
76	0					0	0	0	0	0
80	1.0	1	0	0	0	50	0	0	0	50
81	0					0	0	0	0	0
86	0					0	0	0	0	0
90	0					0	0	0	0	0

104	0					0	0	0	0	0
119	1.0	3	0	0	0	150	0	0	0	150
120	0					0	0	0	0	0
121	4.0	0	0	0	1	0	0	0	50	50
	1.0	5	0	0	0	250	0	0	0	250
127	4.0	0	0	0	1	0	0	0	50	50
129	0					0	0	0	0	0
134	0					0	0	0	0	0
135	0					0	0	0	0	0
143	0					0	0	0	0	0
145	0					0	0	0	0	0
147	0					0	0	0	0	0
148	1.0	3	0	0	0	150	0	0	0	150
149	0					0	0	0	0	0
152	0					0	0	0	0	0
	SUM	29	19	41	11	1451	951	2052	550	5004
	Randomly selected sites									
74	0					0	0	0	0	0
75	0					0	0	0	0	0
78	0					0	0	0	0	0
83	0					0	0	0	0	0
85	0					0	0	0	0	0
92	1.0	1	0	0	0	50	0	0	0	50
95	1.0	11	0	0	0	550	0	0	0	550
98	0					0	0	0	0	0
102	2.4	2	0	5	0	100	0	250	0	350

105	0					0	0	0	0	0
107	0					0	0	0	0	0
109	0					0	0	0	0	0
111	0					0	0	0	0	0
114	1.8	3	10	0	0	150	500	0	0	651
117	3.0	0	0	2	0	0	0	100	0	100
125	0					0	0	0	0	0
131	3.0	0	0	1	0	0	0	50	0	50
137	0					0	0	0	0	0
140	4.0	0	0	0	1	0	0	0	50	50
142	0					0	0	0	0	0
	SUM	17	10	8	1	851	500	400	50	1801
	Additional sites									
168	0	0	0	0	0	0	0	0	0	0
173	3.0	0	0	1	0	0	0	50	0	50
	3.0	0	0	1	0	0	0	50	0	50
	SUM	0	0	2	0	0	0	100	0	100
	SUM ALL SITES	46	29	51	12	230 2	1451	2552	600	6905

Table 9: Substrate composition (%) and associated substrate score for sites sampled in Sandy Creek.

Site	Substrate Score	***Percent of Substrate Composition***						
		Gravel	*Cobble*	*BR*	*Sand*	*Silt*	*Boulder*	*Detritus*
		6	*5*	*1*	*2*	*1*	*2*	*1*
	Intentionally selected sites							
68	5.6	60	40					
70	2.6		40	40		20		
76	2.25	5	25	70				
80	5.2	60	30			10		
81	4.35	10	70	15	5			
86	3	20	25	50		5		
90	4.7	50	30	20				
104	4	20	50	20		10		
119	5.15	70	15		5	10		
120	4.55	70			5	25		
121	4.35	50	20		5	25		
127	4.25	45	25	25		5		
129	4.85	65	10		5	5	15	
134	3.7	50	5	40		5		
135	3.05	25	20	50		5		

143	2.8	20	20	60			
145	2.2	5	20	55		5	15
147	5.3	50	45			5	
148	5.5	70	25			5	
149	5.45	85	5			10	
152	4.45	40	30		5	5	20
	Randomly selected sites						
74	1.5	10		90			
75	2.5	25		25	25	25	
78	4.6	40	40	20			
83	3.5	10	50	40			
85	4.6	40	40	20			
92	3.25	25	25	50			
95	3.6	20	40	40			
98	3.5	15	40	30	15		
102	4.05	20	50	20	5	5	
105	2.4		30		20	50	
107	1					100	
109	4.6	40	40	20			
111	4.1	20	50		10	20	
114	3.5	40	10		10	40	

117	2	10	10		10	70	
125	5.05	25	70			5	
131	4.3	40	30			20	10
137	3.35	25	30			35	
140	4.65	45	35	10		10	
142	1			100			
	Additional sites						
168	2.4	10	20	60	10		
173	4.3	35	35			15	15

Table 10: Date, water temperature, dissolved oxygen content, velocity, turbidity, and substrate score at sampled sites during the study period.

Site	Date	Temp. °C	DO mg/L	Velocity m/sec	Turbidity NTU	Substrate Score
	Intentionally selected sites					
68	4/22/07	12.0	10.43	0.81	0.1	5.6
	5/12/07	14.0	10.29	0.92	0.0	
	8/9/07	20.4	7.54	1.05	0.0	
	10/26/07	10.8	10.54	0.77	0.1	
	12/7/07	0.3	11.96	1.03	0.2	
70	6/18/07	23.5	7.22	0.72	1.4	2.6
	8/8/07	23.6	7.54	1.02	0.0	
	9/14/07	19.7	8.18	0.84	1.5	
	10/26/07	12.6	8.33	0.12	0.0	
	12/7/07	-0.1	11.96	1	2.4	
76	5/21/07	16.7	9.75	1.63	0.0	2.25
80	5/5/07	14.0	9.07	0.35	0.2	5.2
81	5/28/07	23.5	13.84	1.58	1.2	4.35
86	6/1/07	21.1	11.1	0.67	0.0	3
90	5/19/07	15.5	9.76	1.64	0.0	4.7
	6/1/07	20.3	9.26	0.04	7.1	0

104	5/13/07	13.0	7.79	0.6	0.3	4
119	5/31/07	20.1	8.22	0.57	8.0	5.15
	6/6/07	22.4	8.77	1.04	0.9	5.15
120	7/6/07	23.2	8.83	1.02	8.8	4.55
121	11/6/06	5.0	11.21	0.87	22.6	4.35
	5/2/07	14.3	12.75	0.73	0.3	0
127	8/3/07	25.3	8.6	0.76	9.5	4.25
129	8/3/07	26.0	8.05	1.23	10.5	4.85
134	8/3/07	26.4	8.55	0.86	5.9	3.7
135	8/3/07	26.4	7.56	0.23	12.4	3.05
143	7/27/07	23.7	3.86	0	0.0	2.8
145	8/2/07	23.8	1.82	0	0.0	2.2
147	8/2/07	26.9	8.41	1.06	15.3	5.3
148	5/2/07	13.8	11.48	0.54	0.4	5.5
149	5/28/07	19.6	7.7	1.54	6.2	5.45
152	8/2/07	28.4	9.18	0.72	2.3	4.45
	Randomly selected sites					
74	5/26/07	21.1	7.04	0.21	0.2	1.5
	6/7/07	22.4	8.29	0.21	0	0
75	6/16/07	22.0	10.03	0.45	0.9	2.5
78	6/18/07	25.6	14.51	1.53	4.3	4.6
83	6/28/07	28.2	11	0.52	2.3	3.5
85	6/28/07	27.4	12.1	2.23	0.3	4.6

92	5/5/07	14.0	8.86	0.48	0.1	3.25
		19.8, trib				
	6/3/07	16.8	11.13	0.42	3.7	0
95	4/28/07	11.5	10.07	1.63	0.2	3.6
98	5/31/07	24.4	8.95	1.5	1.4	3.5
102	5/13/07	13.0	8.62	0.45	0.3	4.05
105	5/21/07	16.2	9.75	1.59	0.2	2.4
107	5/21/07	17.0	9.21	1.44	0.4	1
109	6/9/07	24.3	6.8	0.51	47.6	4.6
111	6/9/07	25.4	4.53	0.42	48.2	4.1
114	5/2/07	14.7	13.32	0.58	0.1	3.5
117	6/6/07	18.2	7.5	0.09	4.6	2
125	8/2/07	25.1	8.22	0.45	4.0	5.05
131	8/3/07	26.5	8.4	0.92	6.2	4.3
137	5/19/07	19.2	5.8	0.67	0.0	3.35
140	5/28/07	18.5	7.62	1.1	0.6	4.65
142	7/27/07	20.1	6.2	0	0.0	1
	Additional sites					
168	11/6/06	6.0	11.67	1.07	23.5	2.4
173	7/14/07	19.9	7.25	0.82	0.2	4.3
	8/8/07	23.9	6.24	0.5	0.1	0

Table 11: Physical habitat and vegetation data for sites sampled in Sandy Creek. Vegetation codes: C = filamentous algae, E = American waterweed (*Elodea* spp.), V = tapegrass (*Valisneria*), M = Eurasian watermilfoil (*Myriophyllum spicatum*), N = water naiad (*Najas flexilis*), P = pond weed (*Potamogeton* spp.).

				Percent of Creek Composition					
Site	**Date**	**Depth (m)**	**Width (m)**	***Run***	***Riffle***	***Pool***	***Falls***	**Instream Vegetation%**	**Instream Wood%**
	Intentionally selected sites								
68	6/23/2006	0-1	7	70	20	10	0	0	0
70	6/23/2006	0-2	8	0	0	70	30	0	0
76	7/7/2006	0-1	15	60	40	0	0	75%, CM	0
81	7/11/2006	0-1	20	50	50	0	0	80% CNM	0
86	7/19/2006	0.5-1.5	15	50	50	0	0	20% EM	5
90	7/19/2006	0-0.5	4	30	70	0	0	0	2
104	7/21/2006	0.5-1	10	50	50	0	0	50% V	5
119	8/1/2006	0-1	8	30	70	0	0	0	5
120	8/1/2006	0-1	5	80	20	0	0	5% V	10
127	9/9/2006	0-0.5	5	60	20	20	0	0	30
129	9/9/2006	0-0.5	10	90	10	0	0	0	10
135	9/9/2006	0-0.5	5	100	0	0	0	0	2
143	9/21/2006	0-1	7	15	10	50	25	0	0
145	9/21/2006	0-1.5	5	30	0	40	30	0	0
147	9/21/2006	0-1	5	60	20	20	0	0	0
148	9/21/2006	0-0.5	4	90	10	0	0	0	0
152	9/21/2006	0-0.5	5	60	40	0	0	0	0

	Randomly selected sites								
74	6/26/2006	0-1	8	60	40	0	0	95%, C	0
75	6/26/2006	0-2	20	0	20	80	0	90%, C	5
79	7/7/2006	0-1	20	100	0	0	0	80%, C	0
83	7/11/2006	0-1.5	8	50	50	0	0	30% CM	5
85	7/11/2006	0-1	6	40	60	0	0	50% C	0
95	7/20/2006	0-1.5	10	60	20	20	0	40% VCP	0
98	7/20/2006	0-1	15	80	20	0	0	30% V	10
102	7/21/2006	0-1.5	12	60	20	20	0	0	2
105	7/26/2006	1-2	10	100	0	0	0	0	2
107	7/26/2006	0.5-2	8	100	0	0	0	0	10
109	7/26/2006	0.5-1.5	8	100	0	0	0	20% V	10
114	7/26/2006	0.5-2	6	100	0	0	0	0	10
117	8/1/2006	0-0.5	10	100	0	0	0	0	5
125	9/9/2006	0-1	7	0	30	70	0	15% V	10
131	9/9/2006	0-1	10	80	0	20	0	0	0
140	9/18/2006	0-0.5	8	0	100	0	0	0	2
142	9/21/2006	0-0.5	8	25	25	50	0	0	0

Table 12: Water temperature (^{o}C) and dissolved oxygen (mg/L) content of the Erie Canal at its confluences with the east and west branches of Sandy Creek.

	West Branch		East Branch	
Depth to top of Sluice Gates	3.5m		4.2m	
Surface Temp	23.7	7.89	24.1	7.81
1m depth Temp	23.6	7.83	24.0	7.64
2m depth Temp	23.6	7.65	24.0	7.60
3m depth Temp	23.6	7.39	23.9	7.60
Bottom Temp	23.6	6.93	23.9	7.55
Discharge Temp	23.7	8.13	23.9	8.20

Table 13: Count, mean, and standard error for habitat variables of Sandy Creek during the study period.

Category	**Intentionally selected sites**			**Randomly selected sites**		
	Count	**Mean**	**SE Mean**	**Count**	**Mean**	**SE Mean**
CanopyCover%	25	39.7	7.94	22	33.7	7.19
BankCover	25	2.1	0.42	22	2.6	0.54
InstreamWood%	25	6.5	1.30	22	4.5	0.95
InstreamVeg%	25	12.0	2.40	22	27.1	5.77
SubstrateScore	25	4.2	0.84	22	3.3	0.70
Temp^{o}C	25	21.0	4.21	22	20.5	4.38
DO (mg/L)	25	8.7	1.74	22	9.0	1.92
Velocity (m/s)	25	0.8	0.16	22	0.8	0.17
Turbidity (NTU)	25	1.4	0.28	22	5.3	1.12

Figures

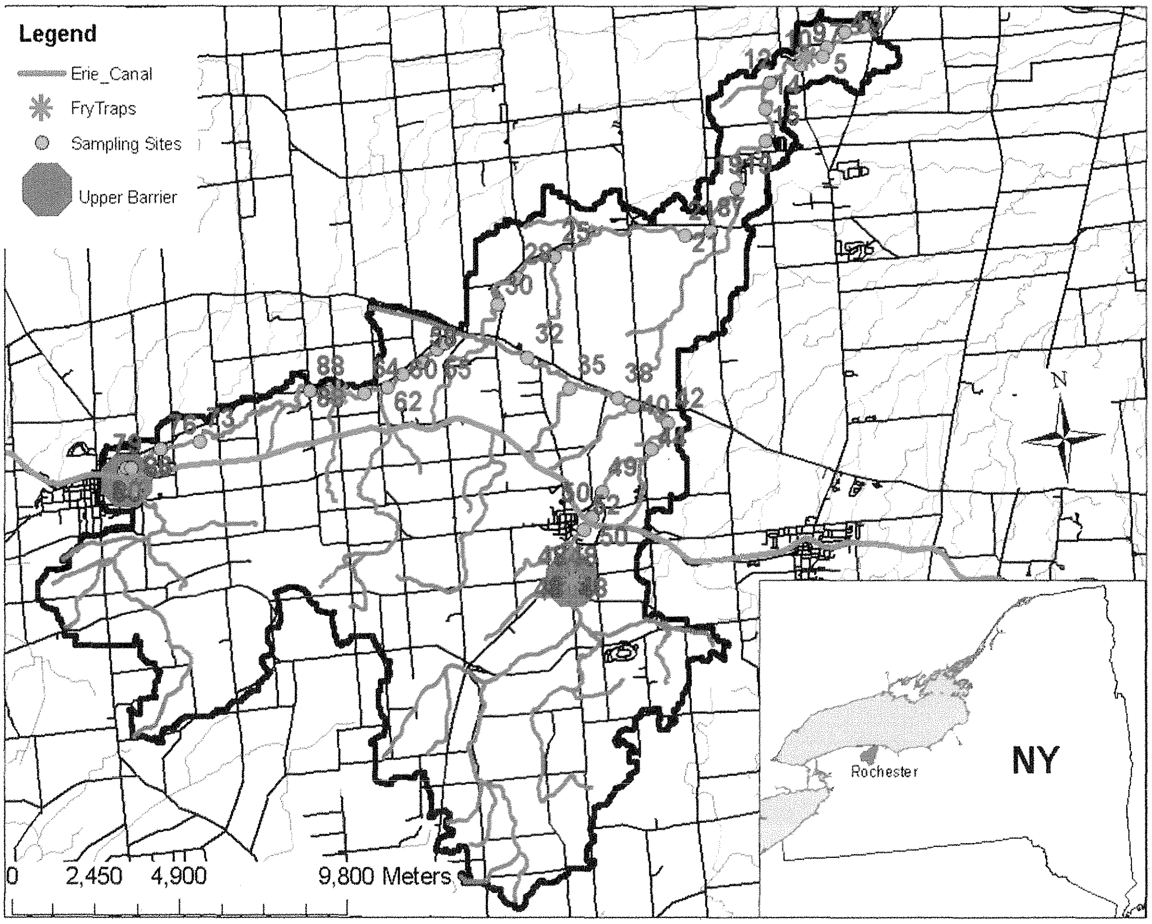


Figure 1: Sandy Creek's watershed, sampling sites by number, impassable fish migration barriers, and locations of fry emergence traps.

Figure 2: Examples of easily erodible soils created through intensive land use within the riparian zone and watershed.

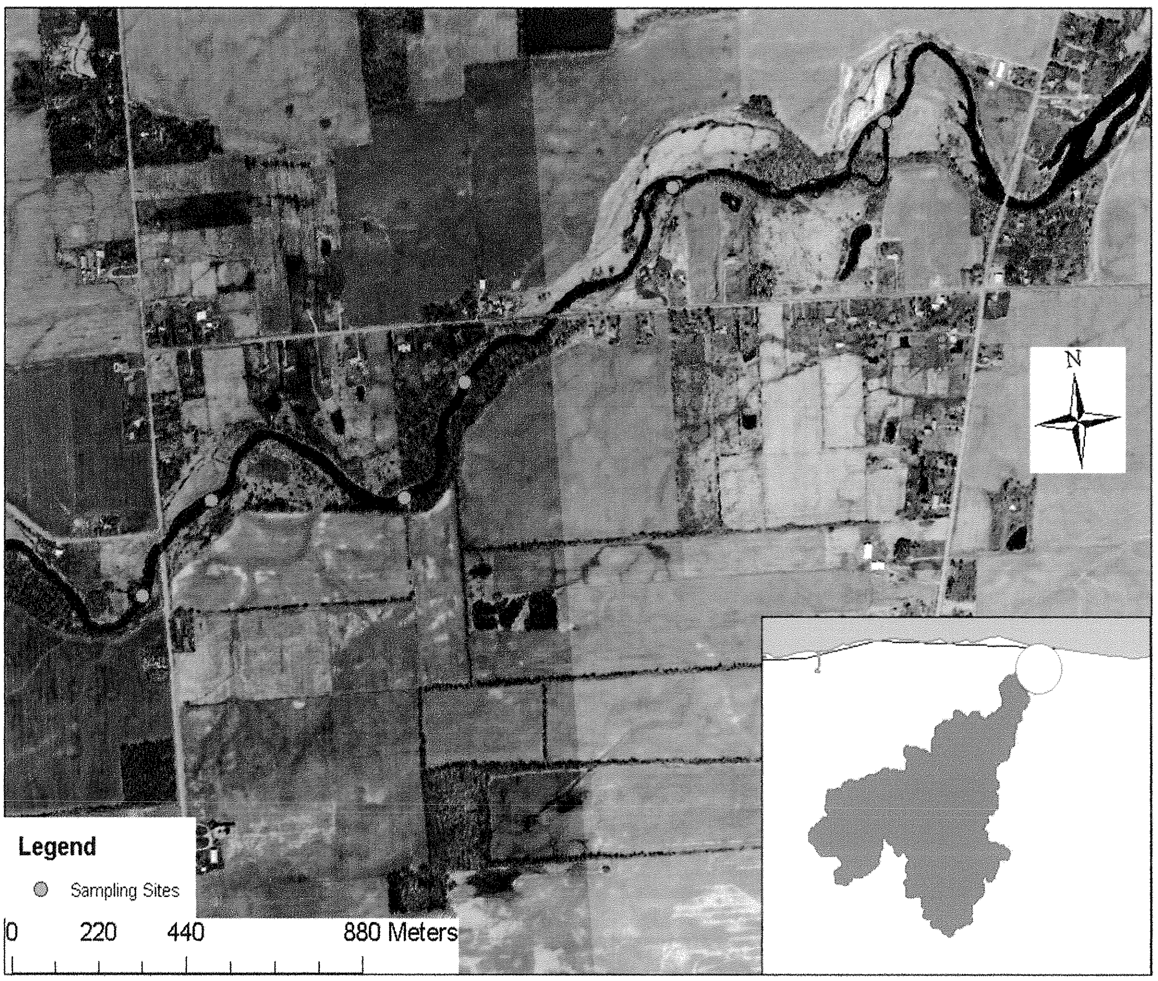


Figure 3: Locations of erosive areas in relation to the watershed and sampling sites.

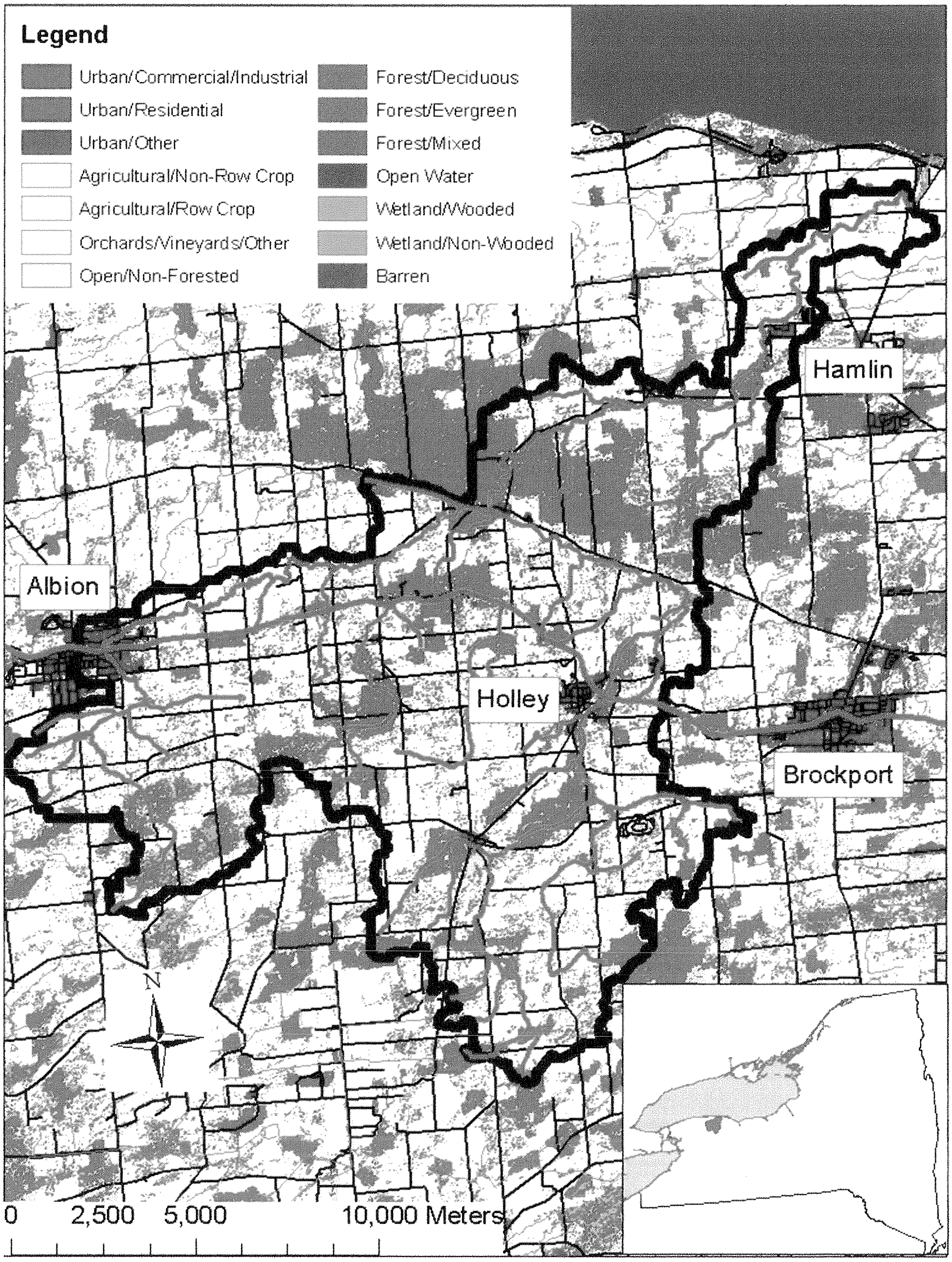


Figure 4: Land use types and their distribution within Sandy Creek's watershed.

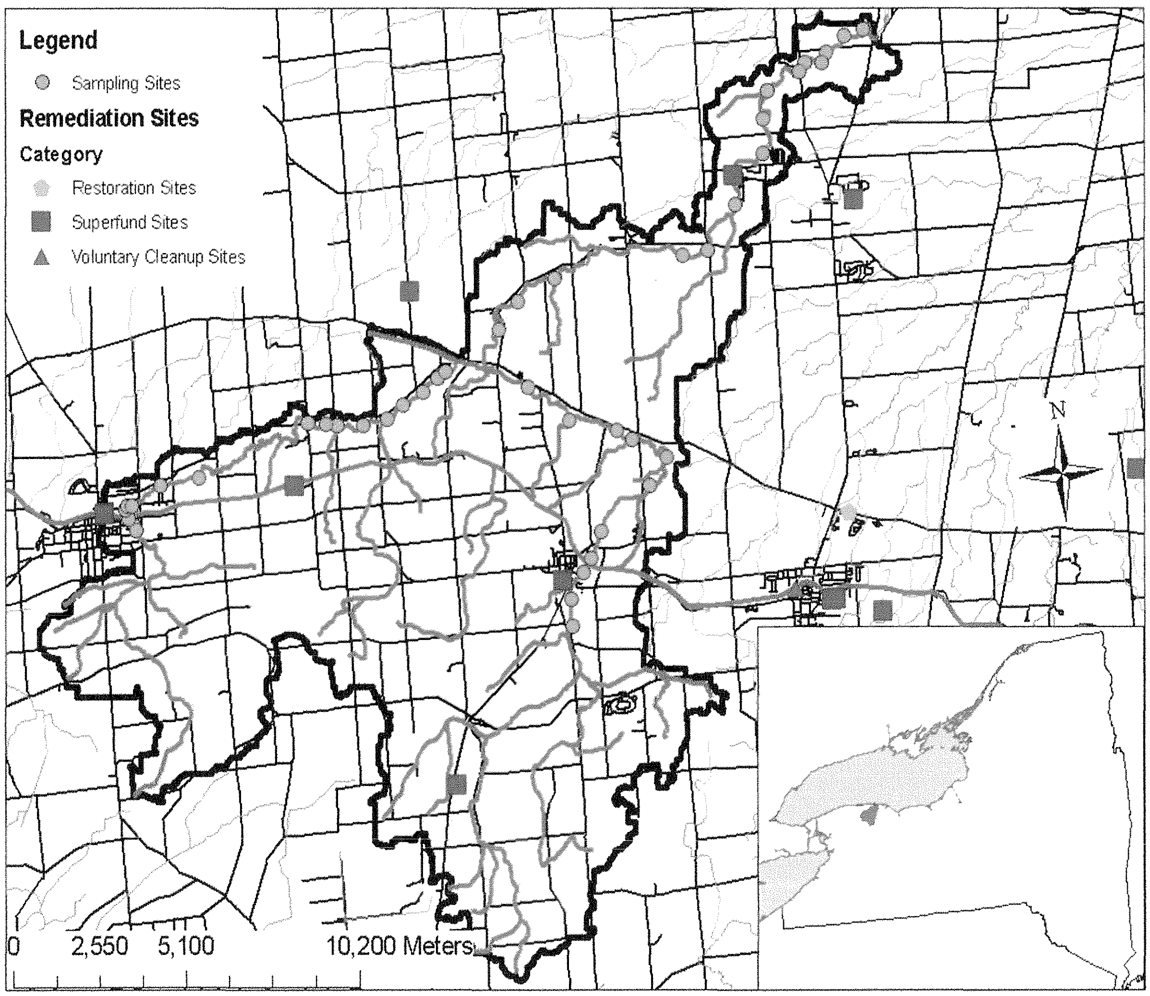


Figure 5: NYDEC classified hazardous sites by category within Sandy Creek's watershed.

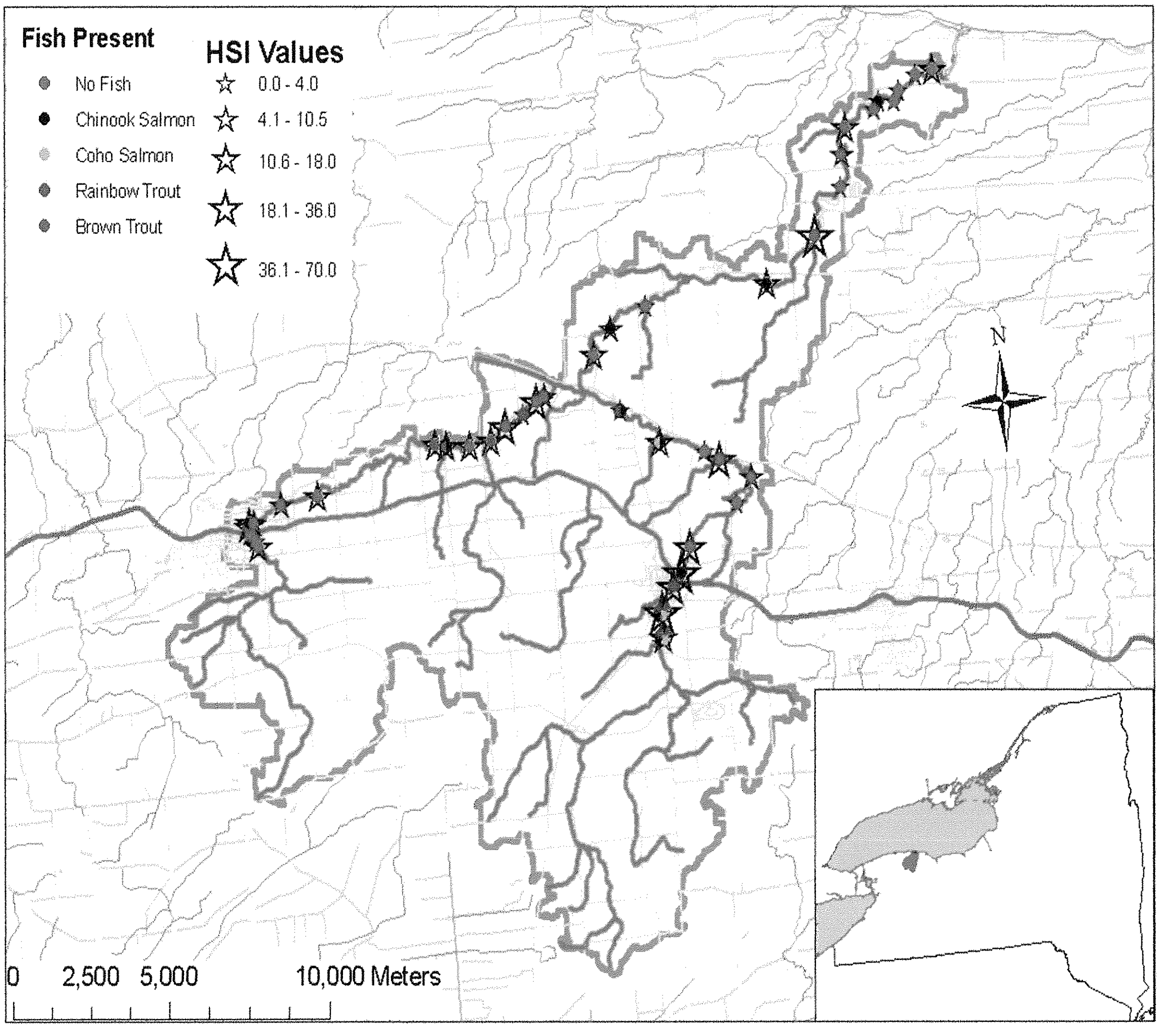


Figure 6: Habitat Suitability Index based on percent canopy and riparian cover and juvenile salmonine presence.

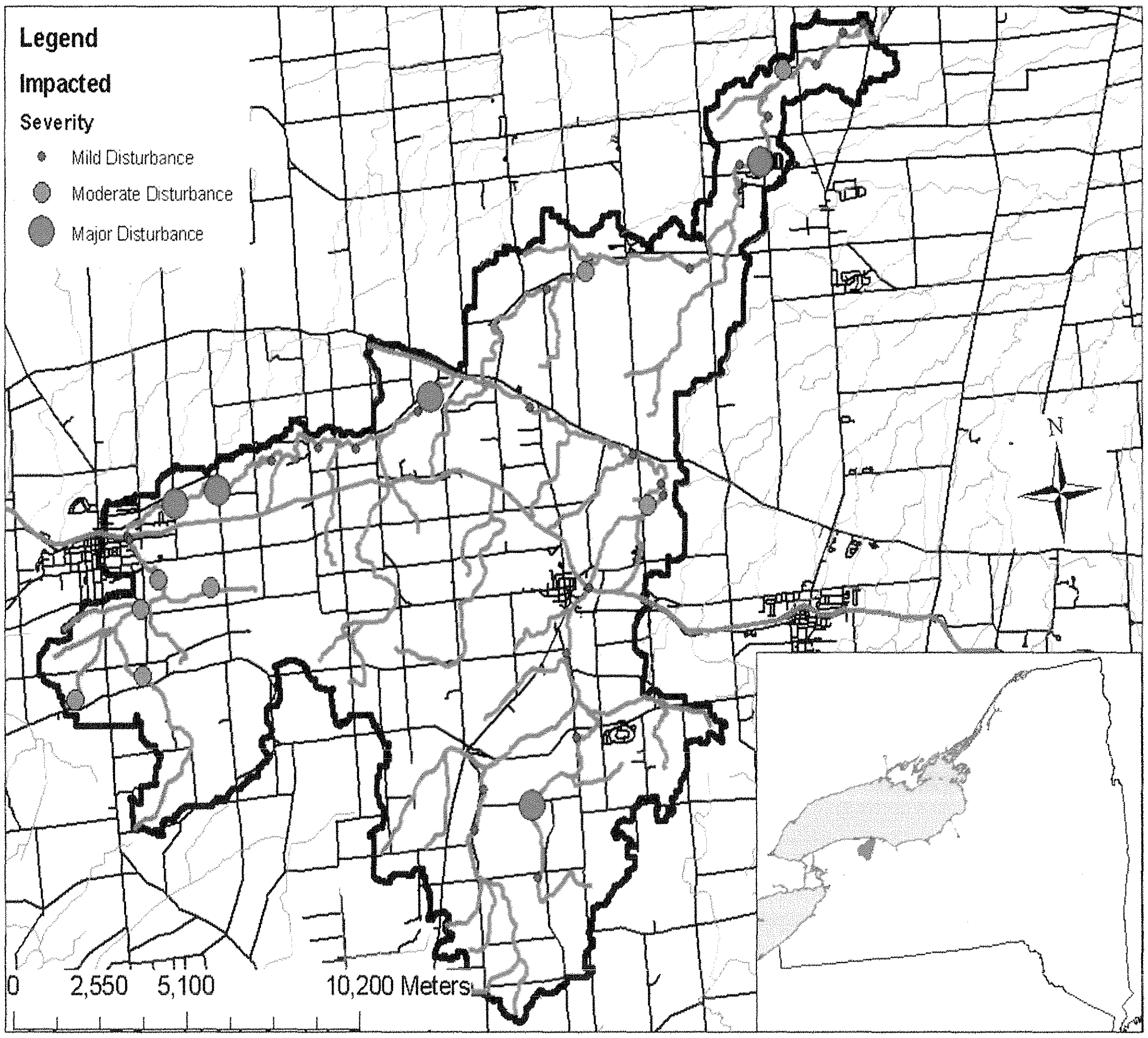


Figure 7: Areas with potential to contribute runoff (sediment, chemicals) to Sandy Creek in a moderate rain event.

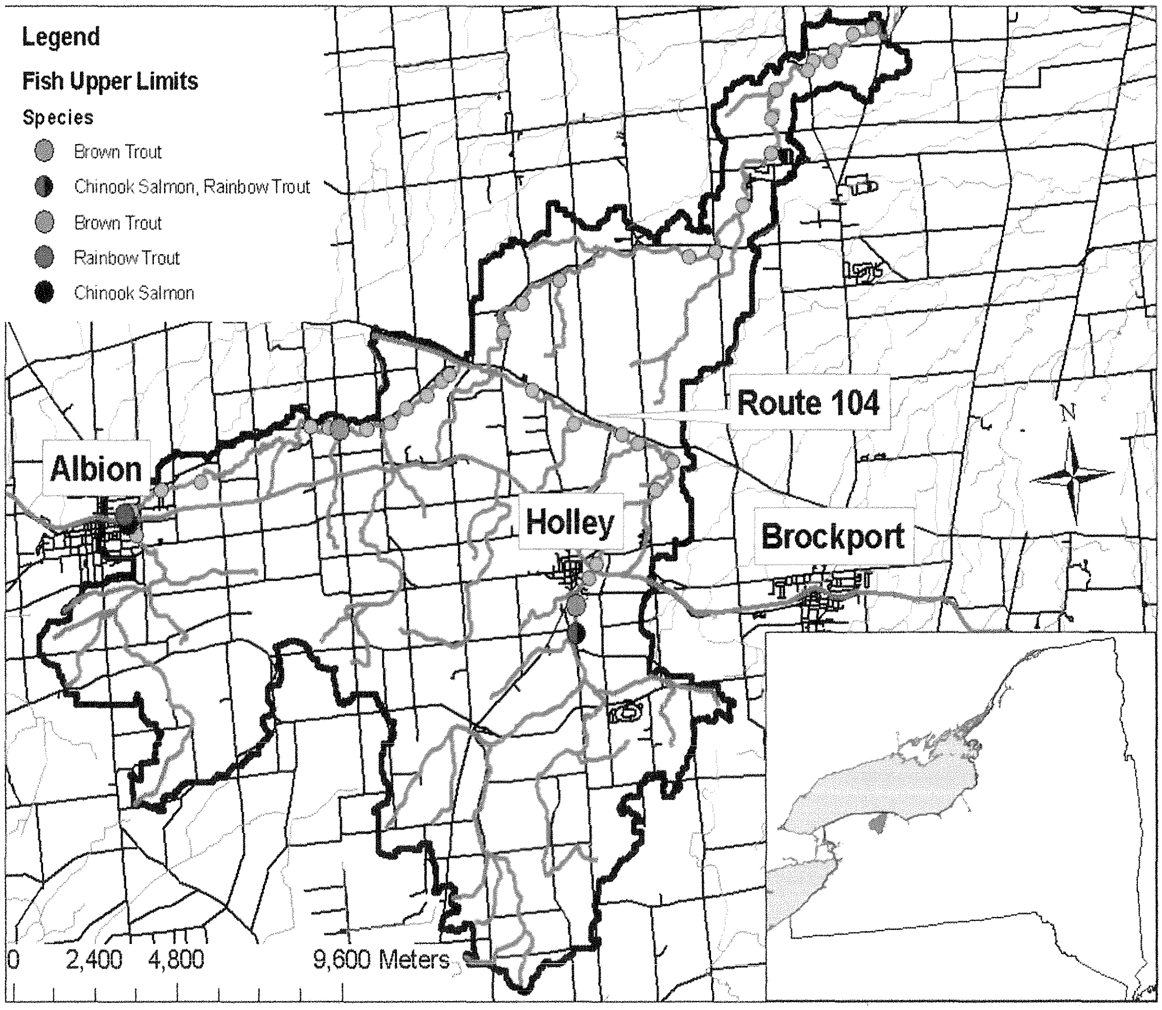


Figure 8: The farthest points upstream reached by migrating adult fishes. Coho salmon were not observed upstream of the creek mouth.

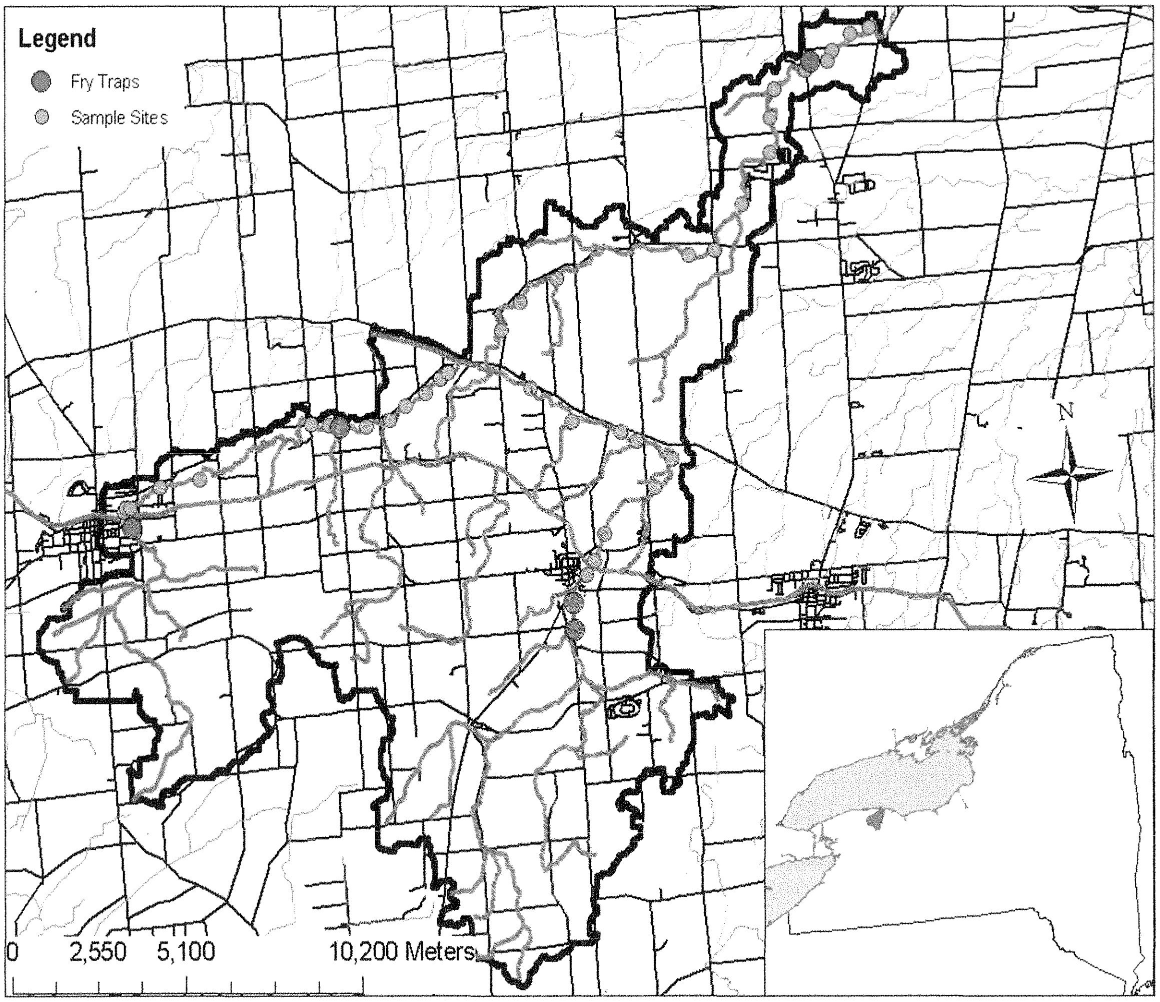


Figure 9: Locations of fry emergence traps in Sandy Creek and the watershed.

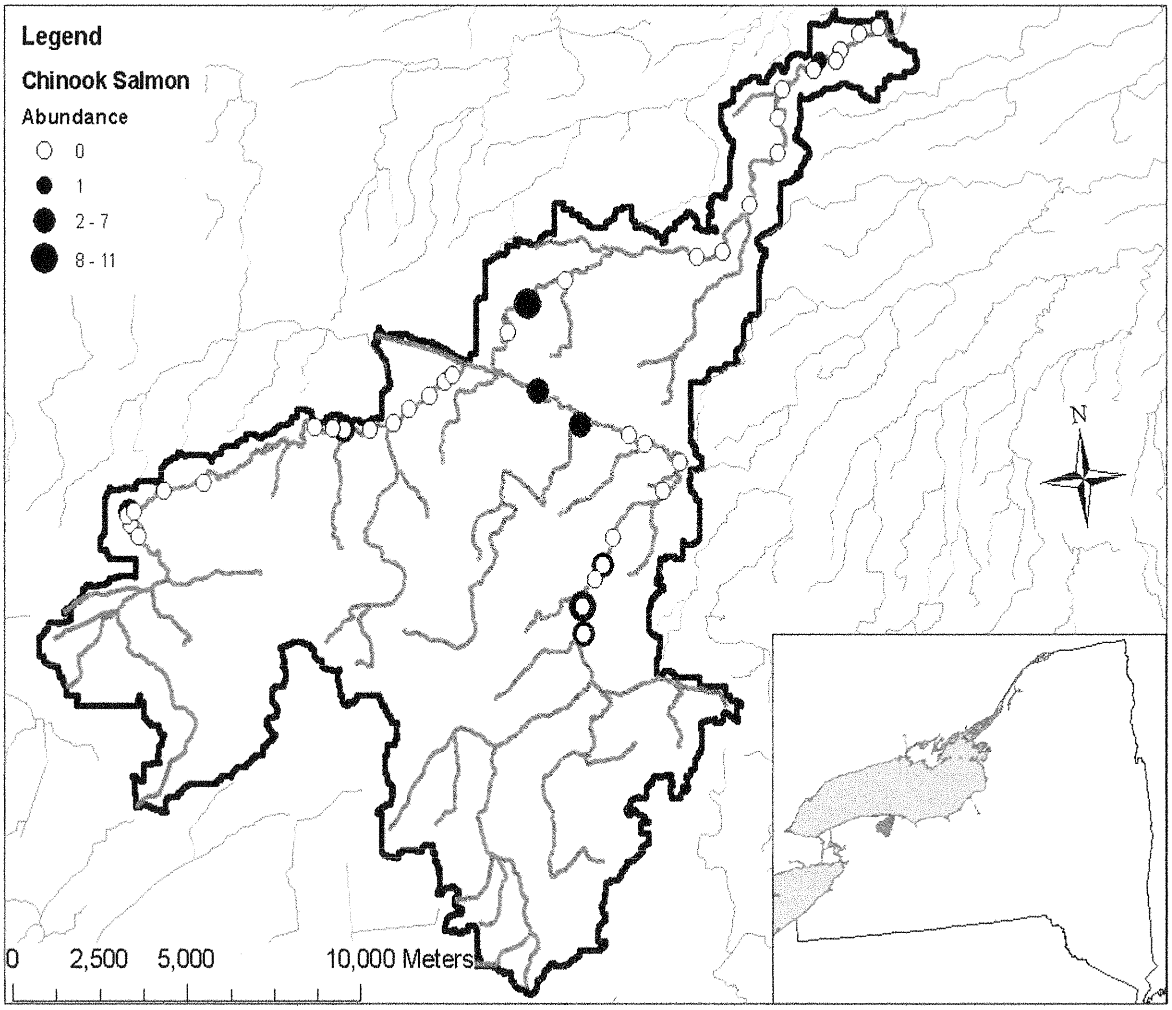


Figure 10: Juvenile Chinook salmon catches by location and quantity.

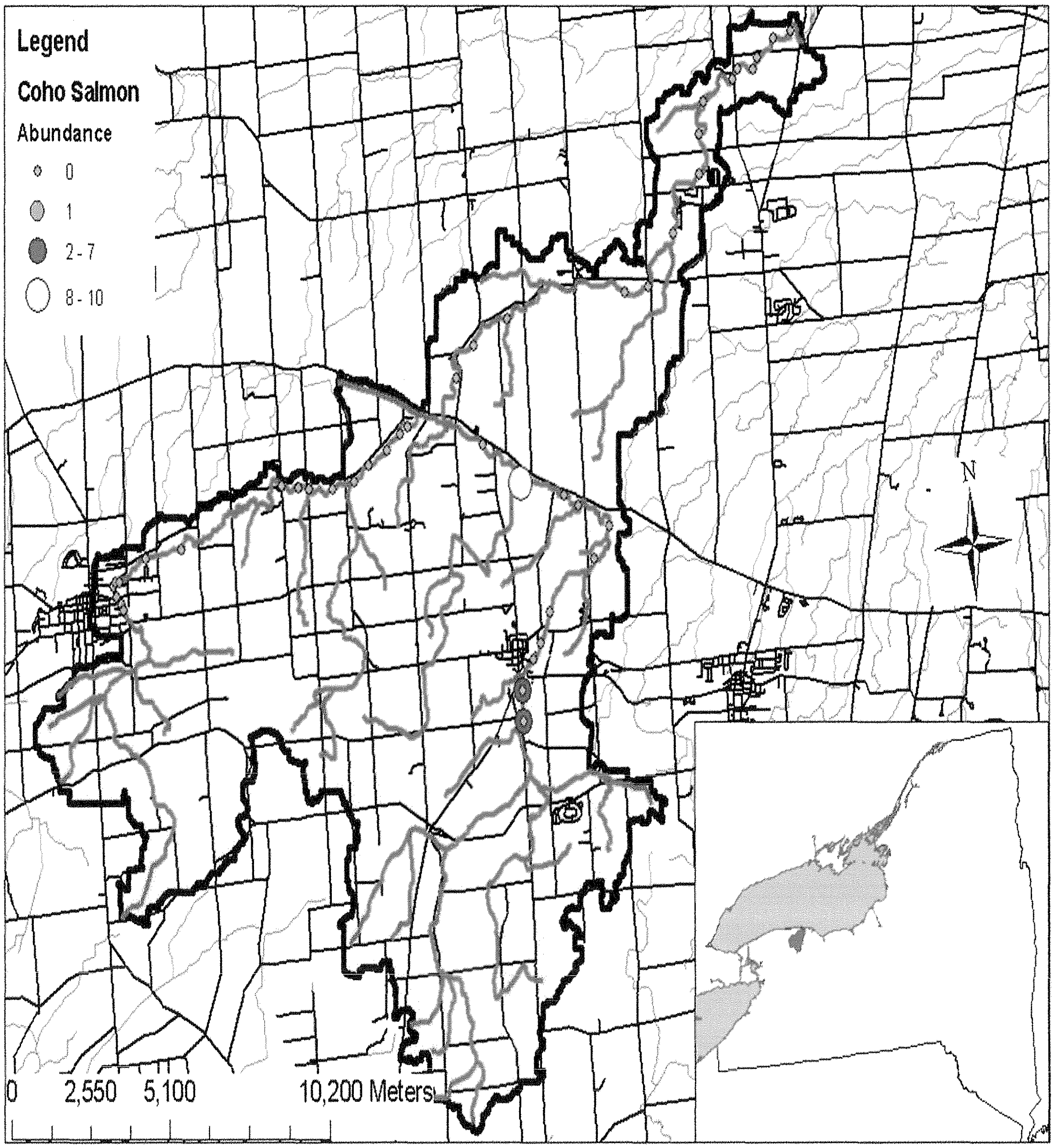


Figure 11: Juvenile coho salmon catches by location and quantity.

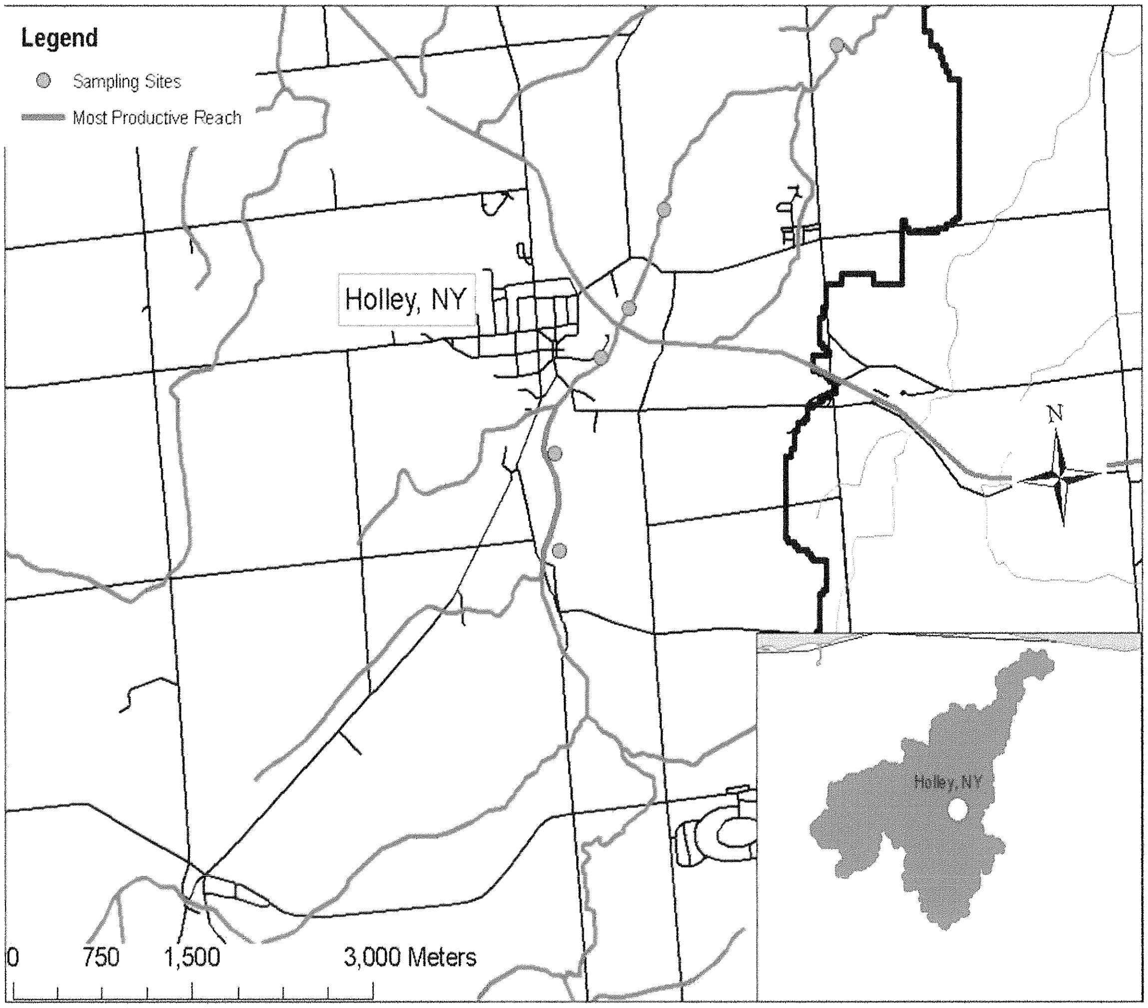


Figure 12: The area of greatest salmonine productivity within Sandy Creek.

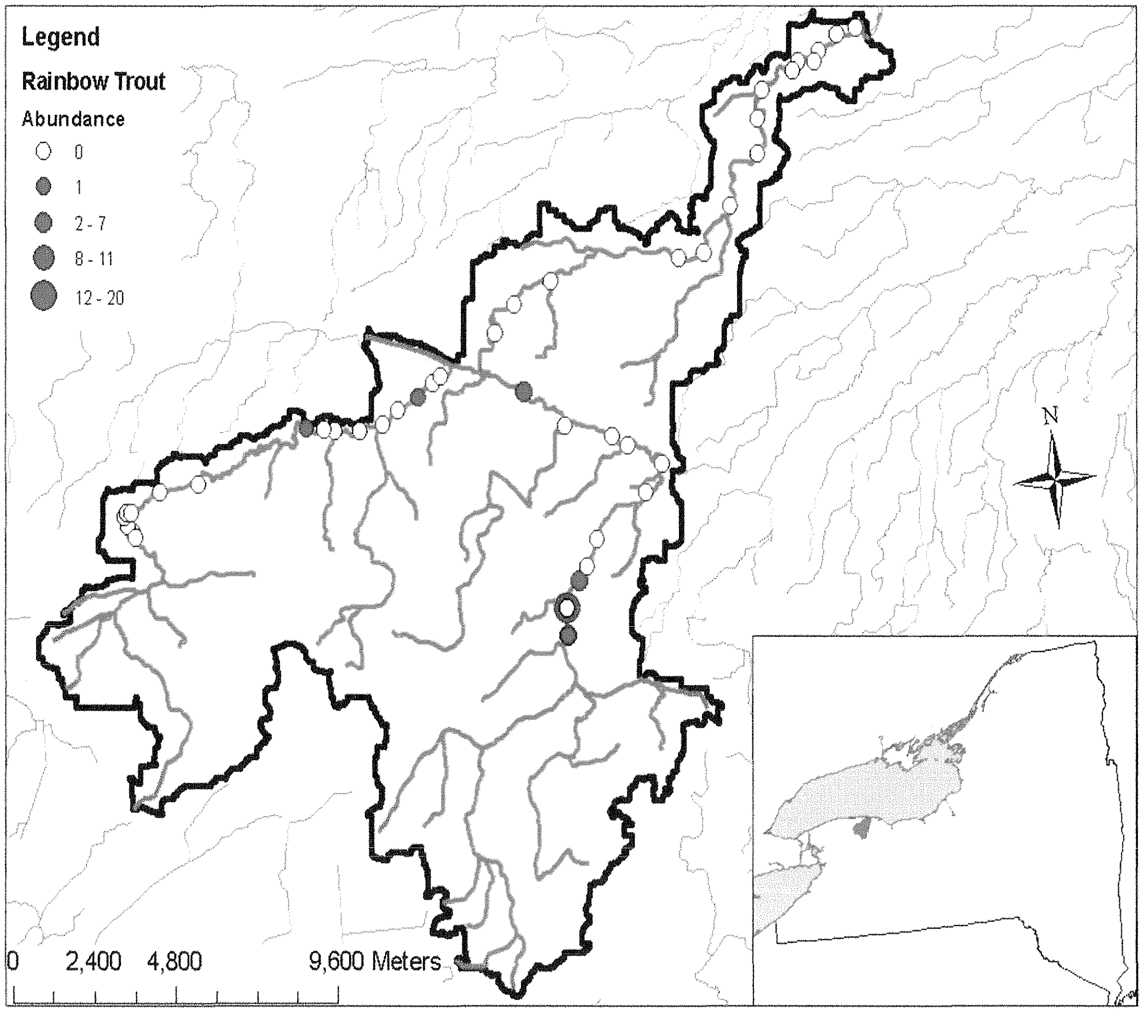


Figure 13: Juvenile rainbow trout/steelhead catches by location and quantity.

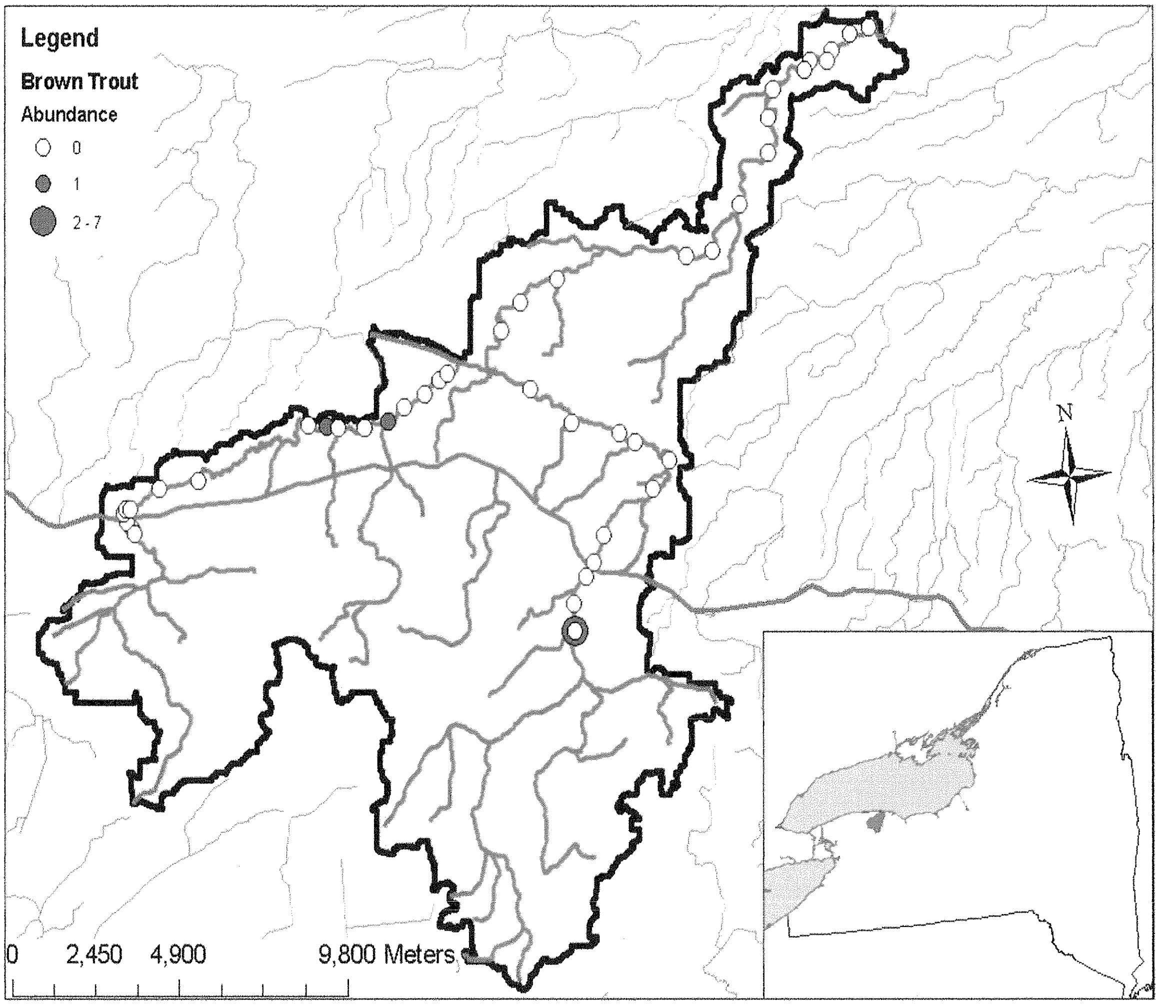
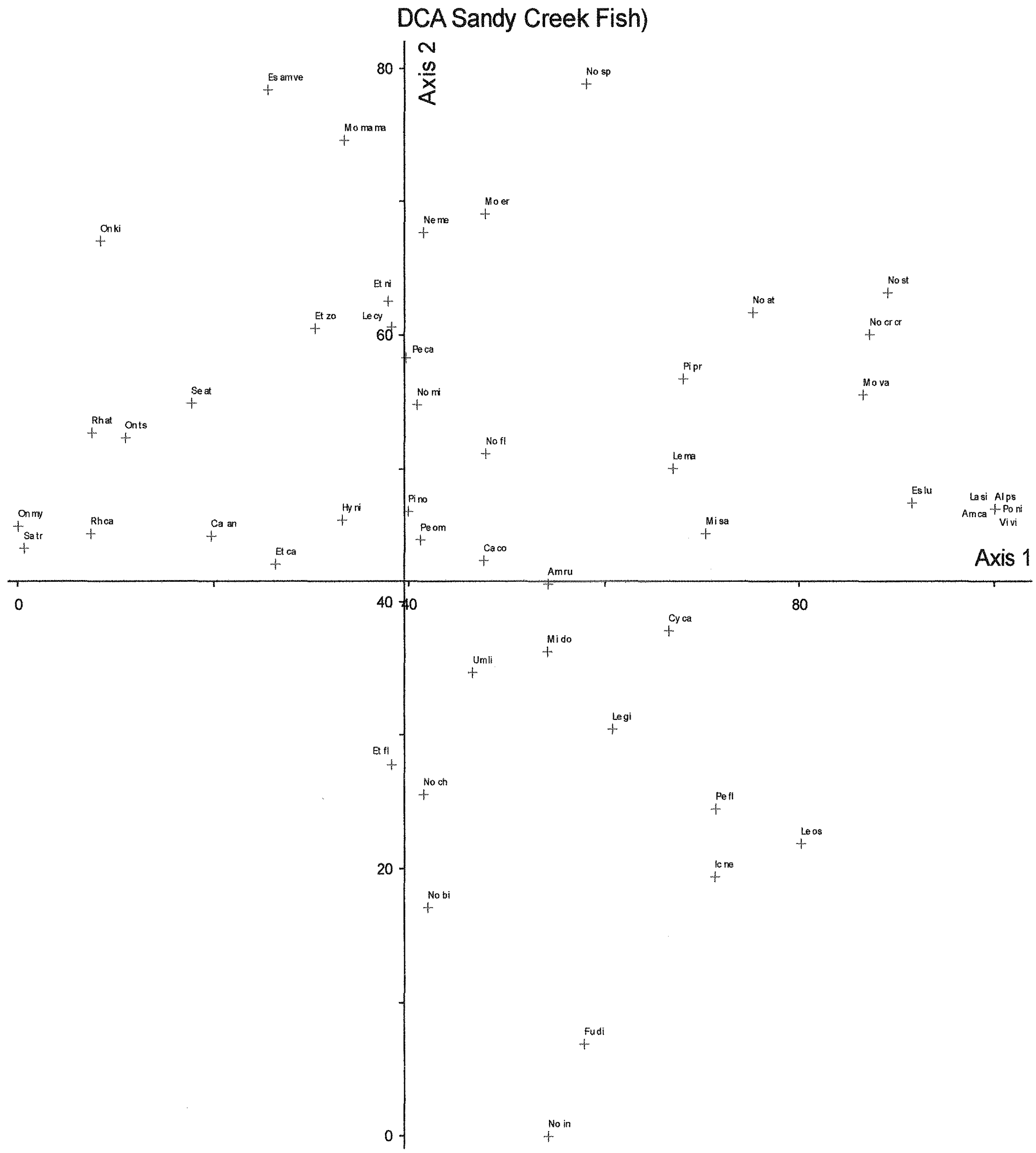


Figure 14: Juvenile brown trout catches by location and quantity.


DCA Sandy Creek Fish)
Axis 2
Axis 1
80
60
40
20
0
0
40
80
Es amve
Mo ma ma
No sp
Mo er
Ne me
On ki
Et ni
Et zo
Le cy
No at
No st
No cr cr
Pe ca
Pi pr
Mo va
Se at
No mi
Rh at
On ts
No fl
Le ma
Es lu
La si
Al ps
Po ni
Am ca
Vi vi
On my
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Ca an
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Pi no
Pe om
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Et ca
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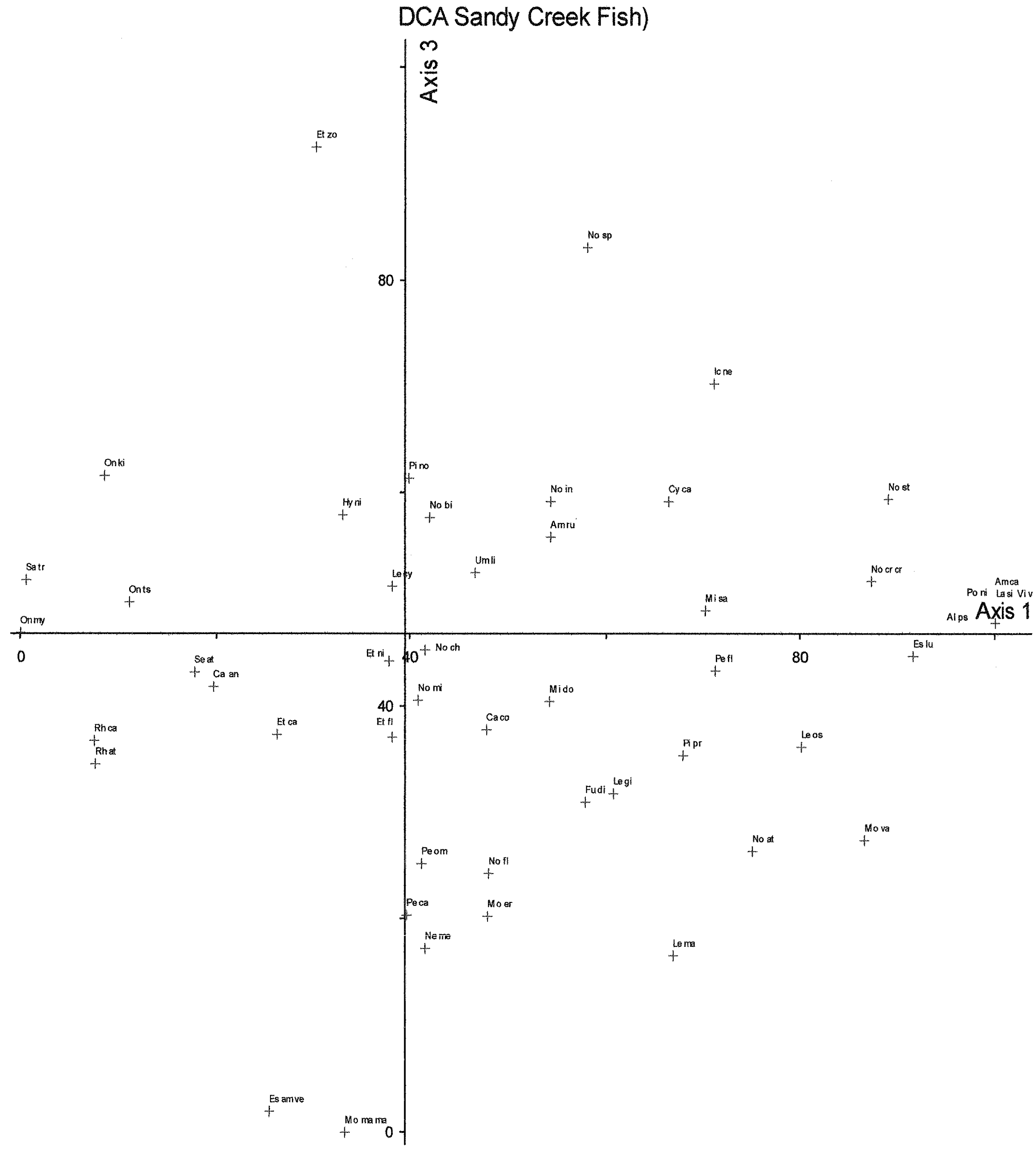
A.


DCA Sandy Creek Fish)
Axis 3
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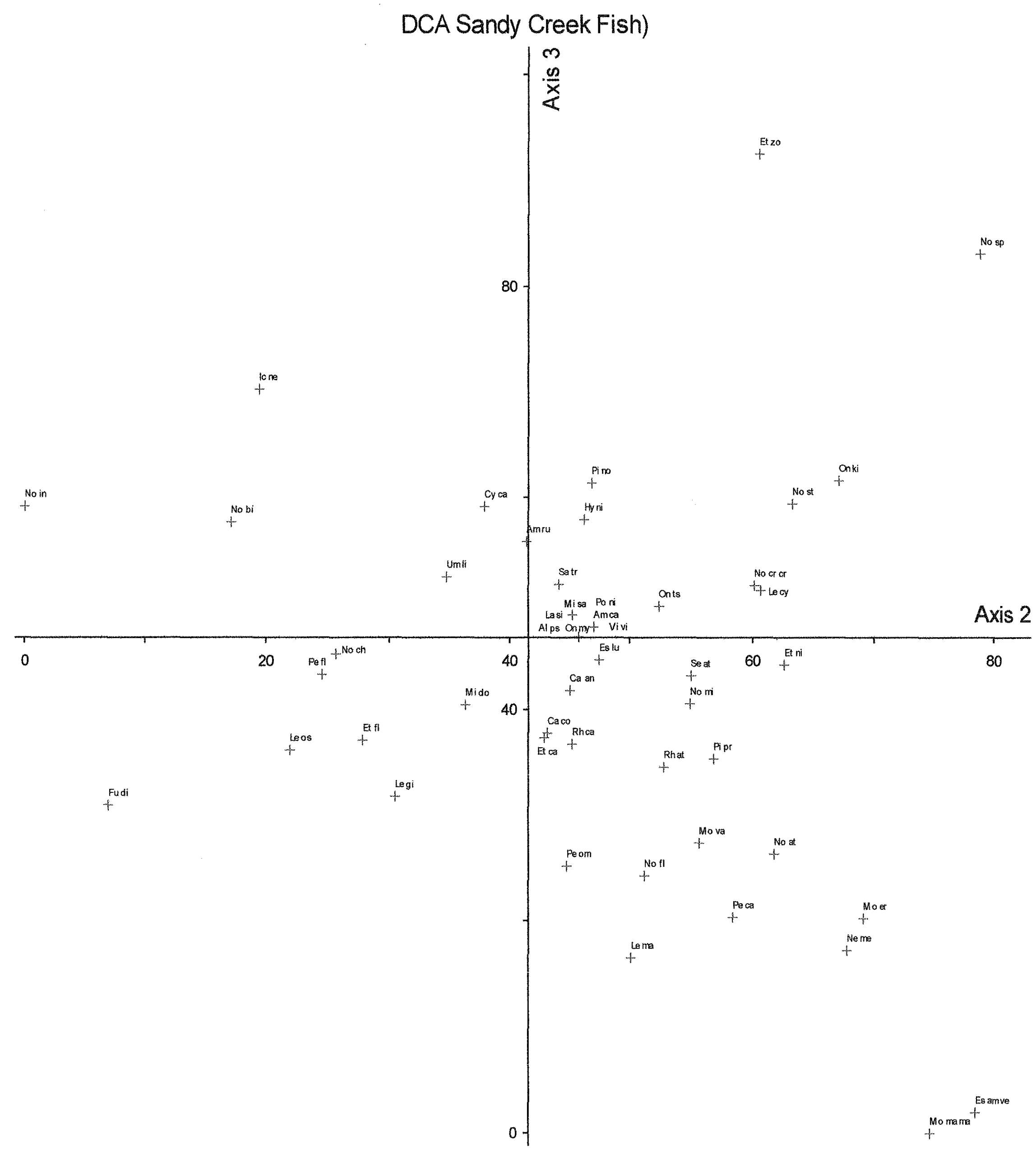
B.



C.

Figures 15 A, B, C: Detrended correspondence analysis for all species.

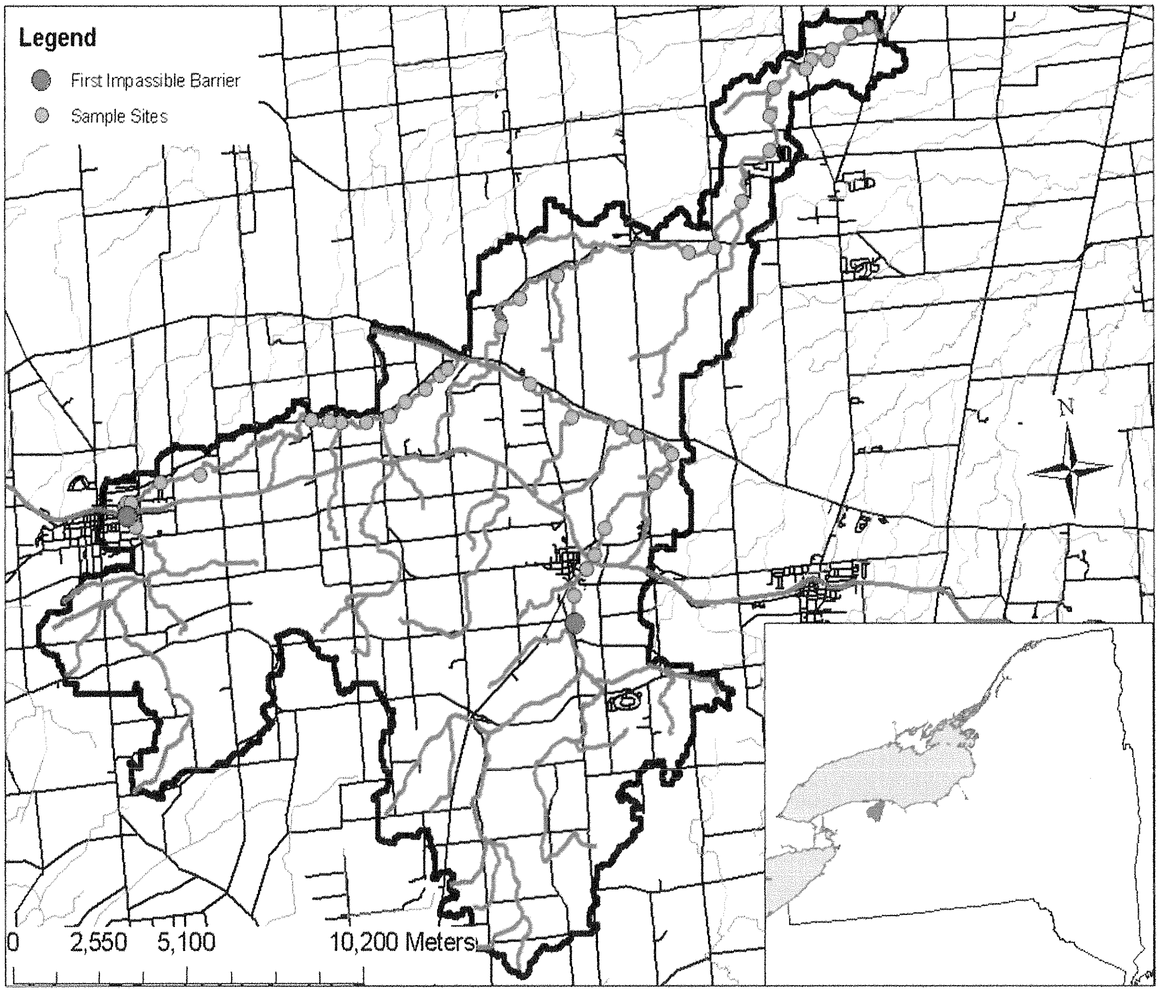


Figure 16: First impassable barrier to upstream fish migration in Sandy Creek.

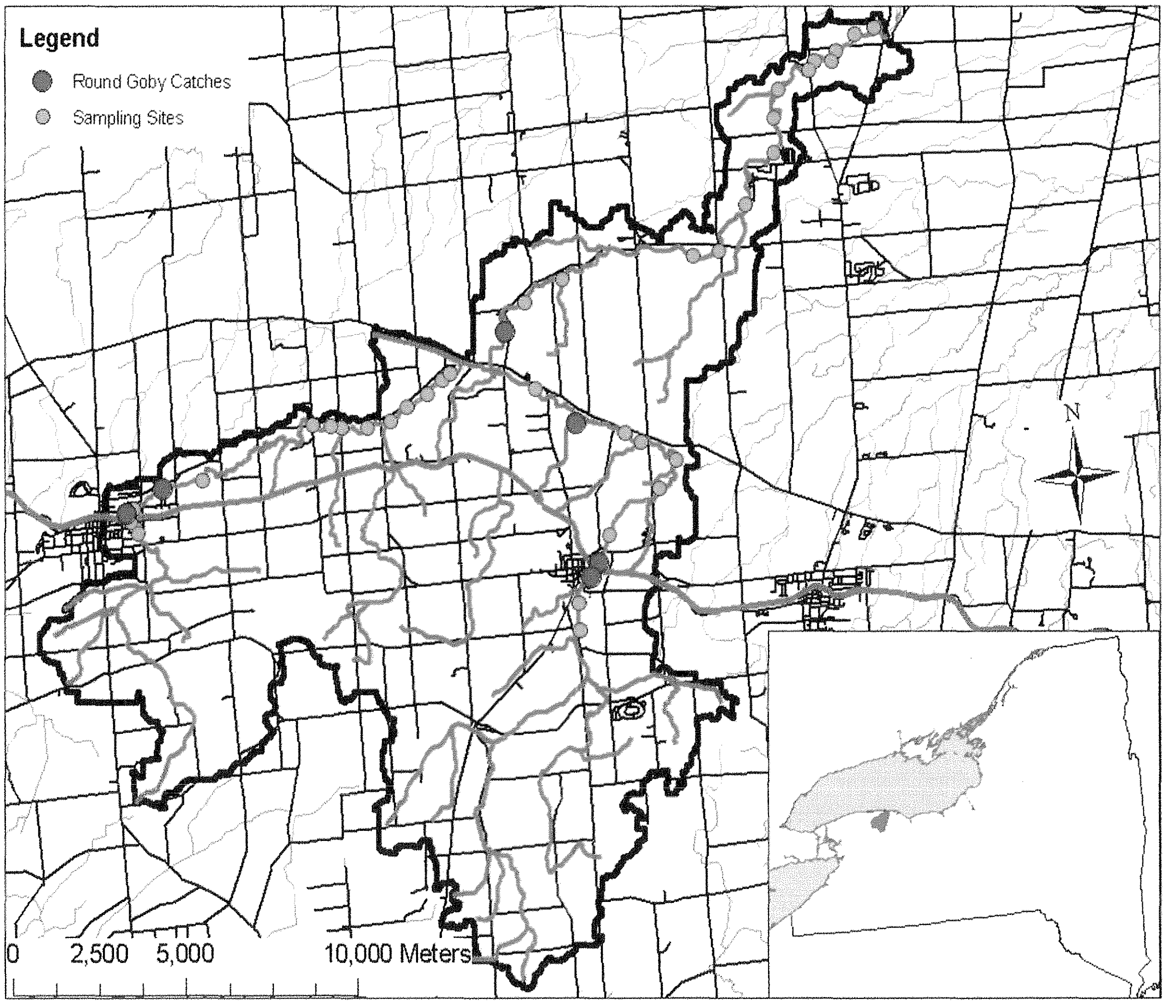


Figure 17: Sites where invasive round gobies were captured.

Appendices

Appendix 1—Chinook Salmon: GLM ANOVA and Best Subsets Regression Results.

Statistix 8.0 3/20/2008,
2:40:18 PM

Analysis of Variance Table for Chinook

Source	DF	SS	MS	F	P
Treatment	1	0.20408	0.20408	0.04	0.8507
Season	1	1.00395	1.00395	0.18	0.6766
Treatment*Season	1	0.00000	0.00000	0.00	1.0000
BankCover	1	4.81157	4.81157	0.85	0.3636
Canopy	1	0.41873	0.41873	0.07	0.7875
DO	1	0.00822	0.00822	0.00	0.9698
Flow	1	0.32386	0.32386	0.06	0.8126
InVeg	1	0.71089	0.71089	0.13	0.7255
InWood	1	2.15798	2.15798	0.38	0.5415
IntDistm	1	3.96304	3.96304	0.70	0.4091
Substrate	1	3.94079	3.94079	0.70	0.4104
Temp	1	54.6998	54.6998	9.65	0.0039
Turbid	1	0.01062	0.01062	0.00	0.9657
Error	33	187.063	5.66858		
Total	46				

Note: SS are marginal (type III) sums of squares

Grand Mean 0.9484 CV 251.05

Covariate Summary Table

Covariate	Coefficient	Std Error	T	P
BankCover	-0.34203	0.39401	-0.87	0.3916
Canopy	-0.00602	0.01917	-0.31	0.7554
DO	-0.02586	0.22109	-0.12	0.9076
Flow	0.17496	0.82192	0.21	0.8327
InVeg	-0.00285	0.01579	-0.18	0.8579
InWood	0.05251	0.05283	0.99	0.3276
IntDistm	0.01866	0.02260	0.83	0.4149
Substrate	0.30836	0.37346	0.83	0.4149
Temp	-0.22224	0.11205	-1.98	0.0557
Turbid	-0.00202	0.04660	-0.04	0.9657

Statistix 8.0 2/29/2008,
10:36:35 AM

Best Subset Regression Models for Chinook

Forced Independent Variables: (A)Temp
Unforced Independent Variables: (B)Canopy (C)BankCover (D)InWood
(E)InVeg
(F)IntDistm (G)DO (H)Flow (I)Turbid (J)Substrate
3 "best" models from each subset size listed.

P	**CP**	**Adjusted R Square**	**R Square**	**Resid SS**	**Model Variables**
2	-1.8	0.2197	0.2367	215.195	A
3	-1.8	0.2404	0.2734	204.835	A J
3	-1.5	0.2346	0.2679	206.404	A C
3	-1.1	0.2259	0.2596	208.736	A F
4	-1.2	0.2494	0.2984	197.803	A D J
4	-0.8	0.2426	0.2920	199.595	A C J
4	-0.8	0.2416	0.2911	199.860	A C F
5	0.0	0.2478	0.3132	193.625	A D F J
5	0.1	0.2474	0.3129	193.710	A C D J
5	0.3	0.2427	0.3085	194.931	A C D F
6	1.2	0.2473	0.3291	189.127	A C D F J
6	1.8	0.2346	0.3178	192.314	A C D G J
6	1.9	0.2334	0.3167	192.633	A B C D J
7	3.1	0.2304	0.3307	188.674	A C D F H J
7	3.1	0.2299	0.3303	188.786	A B C D F J
7	3.1	0.2298	0.3303	188.805	A C D F G J
8	5.0	0.2127	0.3325	188.183	A B C D F H J
8	5.1	0.2110	0.3311	188.579	A B C D F G J
8	5.1	0.2110	0.3311	188.584	A C D F G H J
9	7.0	0.1920	0.3325	188.176	A B C D F G H J
9	7.0	0.1920	0.3325	188.181	A B C D E F H J
9	7.0	0.1920	0.3325	188.181	A B C D F H I J
10	9.0	0.1702	0.3325	188.172	A B C D F G H I J
10	9.0	0.1702	0.3325	188.173	A B C D E F G H J
10	9.0	0.1701	0.3325	188.179	A B C D E F H I J
11	11.0	0.1471	0.3325	188.168	A B C D E F G H I J

Cases Included 47 Missing Cases 0

Appendix 2—Brown Trout: GLM ANOVA and Best Subsets Regression Results.

Statistix 8.0 3/20/2008,
2:44:35 PM

Analysis of Variance Table for Brown

Source	DF	SS	MS	F	P
Treatment	1	0.68533	0.68533	0.76	0.3888
Season	1	2.05513	2.05513	2.29	0.1400
Treatment*Season	1	0.00000	0.00000	0.00	1.0000
BankCover	1	1.27892	1.27892	1.42	0.2414
Canopy	1	0.61707	0.61707	0.69	0.4133
DO	1	0.14013	0.14013	0.16	0.6955
Flow	1	1.17887	1.17887	1.31	0.2603
InVeg	1	0.89241	0.89241	0.99	0.3263
InWood	1	9.86236	9.86236	10.97	0.0022
IntDistm	1	0.45218	0.45218	0.50	0.4831
Substrate	1	0.15568	0.15568	0.17	0.6800
Temp	1	0.00768	0.00768	0.01	0.9269
Turbid	1	0.16821	0.16821	0.19	0.6681
Error	33	29.6572	0.89870		
Total	46				

Note: SS are marginal (type III) sums of squares

Grand Mean 0.2001 CV 473.71

Covariate Summary Table

Covariate	Coefficient	Std Error	T	P
BankCover	-0.20929	0.15688	-1.33	0.1913
Canopy	-0.00404	0.00763	-0.53	0.5998
DO	-0.01331	0.08803	-0.15	0.8807
Flow	0.38275	0.32727	1.17	0.2506
InVeg	0.00527	0.00629	0.84	0.4080
InWood	0.07321	0.02104	3.48	0.0014
IntDistm	-0.00708	0.00900	-0.79	0.4374
Substrate	-0.10178	0.14870	-0.68	0.4985
Temp	-0.05271	0.04462	-1.18	0.2459
Turbid	0.00803	0.01856	0.43	0.6681

Statistix 8.0 2/29/2008,
10:49:45 AM

Best Subset Regression Models for Brown

Forced Independent Variables: (A)InWood
Unforced Independent Variables: (B)Canopy (C)BankCover (D)InVeg
(E)IntDistm
(F)DO (G)Flow (H)Turbid (I)Substrate (J)Temp
3 "best" models from each subset size listed.

P	CP	Adjusted R Square	R Square	Resid SS	Model Variables
2	-3.5	0.2600	0.2761	35.6721	A
3	-2.3	0.2582	0.2904	34.9647	A C
3	-1.9	0.2512	0.2838	35.2939	A E
3	-1.8	0.2489	0.2816	35.4025	A I
4	-0.9	0.2527	0.3015	34.4207	A C I
4	-0.8	0.2503	0.2992	34.5328	A C F
4	-0.7	0.2492	0.2982	34.5847	A C E
5	0.5	0.2477	0.3131	33.8469	A C F G
5	0.6	0.2444	0.3101	33.9940	A C G I
5	0.8	0.2406	0.3066	34.1665	A C F I
6	1.6	0.2464	0.3283	33.0980	A B C F G
6	1.8	0.2435	0.3257	33.2255	A C F G I
6	2.1	0.2378	0.3207	33.4743	A C D F G
7	3.2	0.2370	0.3365	32.6945	A B C F G I
7	3.4	0.2320	0.3322	32.9084	A B C E F G
7	3.5	0.2300	0.3305	32.9919	A B C D F G
8	5.1	0.2204	0.3390	32.5702	A B C E F G I
8	5.2	0.2183	0.3372	32.6596	A B C D F G I
8	5.2	0.2177	0.3367	32.6843	A B C F G H I
9	7.0	0.2008	0.3398	32.5316	A B C D E F G I
9	7.0	0.2000	0.3391	32.5645	A B C E F G I J
9	7.1	0.1999	0.3391	32.5686	A B C E F G H I
10	9.0	0.1794	0.3399	32.5253	A B C D E F G I J
10	9.0	0.1794	0.3399	32.5262	A B C D E F G H I
10	9.0	0.1784	0.3392	32.5638	A B C E F G H I J
11	11.0	0.1567	0.3400	32.5216	A B C D E F G H I J

Cases Included 47 Missing Cases 0

Appendix 3—Coho Salmon: GLM ANOVA and Best Subsets Regression Results.

Statistix 8.0 3/20/2008,
2:43:18 PM

Analysis of Variance Table for Coho

Source	DF	SS	MS	F	P
Treatment	1	0.13323	0.13323	0.04	0.8461
Season	1	0.01175	0.01175	0.00	0.9540
Treatment*Season	1	0.00000	0.00000	0.00	1.0000
BankCover	1	0.14717	0.14717	0.04	0.8384
Canopy	1	0.18656	0.18656	0.05	0.8184
DO	1	5.54810	5.54810	1.59	0.2157
Flow	1	2.70844	2.70844	0.78	0.3842
InVeg	1	1.35917	1.35917	0.39	0.5364
InWood	1	3.71501	3.71501	1.07	0.3092
IntDistm	1	0.42453	0.42453	0.12	0.7292
Substrate	1	0.07828	0.07828	0.02	0.8817
Temp	1	2.19042	2.19042	0.63	0.4334
Turbid	1	0.04950	0.04950	0.01	0.9058
Error	33	114.917	3.48234		
Total	46				

Note: SS are marginal (type III) sums of squares

Grand Mean 0.4651 CV 401.23

Covariate Summary Table

Covariate	Coefficient	Std Error	T	P
BankCover	-0.02892	0.30882	-0.09	0.9260
Canopy	7.567E-04	0.01502	0.05	0.9601
DO	0.18533	0.17329	1.07	0.2926
Flow	-0.57425	0.64421	-0.89	0.3792
InVeg	-0.00682	0.01238	-0.55	0.5856
InWood	0.04722	0.04141	1.14	0.2624
IntDistm	0.00558	0.01772	0.32	0.7547
Substrate	0.08898	0.29271	0.30	0.7630
Temp	-0.05707	0.08783	-0.65	0.5203
Turbid	0.00435	0.03653	0.12	0.9058

Statistix 8.0 2/29/2008,
10:50:50 AM

Best Subset Regression Models for Coho

Unforced Independent Variables: (A)Canopy (B)BankCover (C)InVeg
(D)IntDistm
(E)DO (F)Flow (G)Turbid (H)Substrate (I)Temp (J)InWood
3 "best" models from each subset size listed.

P	CP	Adjusted R Square	R Square	Resid SS	Model Variables
1	-2.3	0.0000	0.0000	139.702	Intercept Only
2	-2.5	0.0293	0.0504	132.659	J
2	-1.9	0.0145	0.0359	134.690	E
2	-1.8	0.0139	0.0354	134.761	I
3	-2.3	0.0531	0.0943	126.528	I J
3	-2.1	0.0479	0.0893	127.222	E J
3	-1.7	0.0384	0.0802	128.493	C E
4	-1.4	0.0585	0.1199	122.948	E I J
4	-1.2	0.0519	0.1138	123.808	C E J
4	-0.9	0.0453	0.1075	124.680	E F J
5	-0.3	0.0579	0.1398	120.173	C E I J
5	-0.0	0.0510	0.1335	121.054	E F I J
5	0.0	0.0496	0.1322	121.234	C E F J
6	1.1	0.0507	0.1539	118.205	C E F I J
6	1.6	0.0367	0.1414	119.948	C D E I J
6	1.7	0.0352	0.1401	120.136	A E F I J
7	3.1	0.0283	0.1551	118.039	C D E F I J
7	3.1	0.0281	0.1549	118.064	C E F H I J
7	3.1	0.0276	0.1545	118.122	A C E F I J
8	5.0	0.0044	0.1559	117.927	A C D E F I J
8	5.0	0.0043	0.1558	117.934	C D E F H I J
8	5.1	0.0037	0.1553	118.011	A C E F H I J
9	7.0	-0.0212	0.1564	117.854	A C D E F H I J
9	7.0	-0.0218	0.1559	117.926	A B C D E F I J
9	7.0	-0.0218	0.1559	117.927	A C D E F G I J
10	9.0	-0.0488	0.1564	117.848	A C D E F G H I J
10	9.0	-0.0488	0.1564	117.851	A B C D E F H I J
10	9.0	-0.0494	0.1559	117.926	A B C D E F G I J
11	11.0	-0.0778	0.1565	117.843	A B C D E F G H I J

Cases Included 47 Missing Cases 0

Appendix 4—Rainbow Trout: GLM ANOVA and Best Subsets Regression Results.

Statistix 8.0 3/20/2008,
2:45:58 PM

Analysis of Variance Table for Rainbow

Source	DF	SS	MS	F	P
Treatment	1	0.46555	0.46555	0.04	0.8356
Season	1	0.11917	0.11917	0.01	0.9163
Treatment*Season	1	0.00000	0.00000	0.00	1.0000
BankCover	1	15.8395	15.8395	1.49	0.2310
Canopy	1	9.29346	9.29346	0.87	0.3567
DO	1	7.52791	7.52791	0.71	0.4063
Flow	1	0.02792	0.02792	0.00	0.9595
InVeg	1	0.04095	0.04095	0.00	0.9509
InWood	1	4.34776	4.34776	0.41	0.5270
IntDistm	1	13.9090	13.9090	1.31	0.2611
Substrate	1	8.80377	8.80377	0.83	0.3696
Temp	1	11.4772	11.4772	1.08	0.3065
Turbid	1	6.34813	6.34813	0.60	0.4453
Error	33	351.033	10.6374		
Total	46				

Note: SS are marginal (type III) sums of squares

Grand Mean 0.9257 CV 352.35

Covariate Summary Table

Covariate	Coefficient	Std Error	T	P
BankCover	-0.67028	0.53974	-1.24	0.2230
Canopy	0.02521	0.02625	0.96	0.3439
DO	-0.28678	0.30287	-0.95	0.3506
Flow	-0.10321	1.12593	-0.09	0.9275
InVeg	0.00499	0.02163	0.23	0.8188
InWood	0.05392	0.07238	0.74	0.4616
IntDistm	0.03975	0.03097	1.28	0.2082
Substrate	0.43177	0.51159	0.84	0.4048
Temp	-0.09243	0.15350	-0.60	0.5512
Turbid	-0.04932	0.06384	-0.77	0.4453

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Best Subset Regression Models for Rainbow

Unforced Independent Variables: (A)Canopy (B)BankCover (C)InVeg
(D)IntDistm
(E)DO (F)Flow (G)Turbid (H)Substrate (I)Temp (J)InWood
3 "best" models from each subset size listed.

P	CP	Adjusted R Square	R Square	Resid SS	Model Variables
1	2.7	0.0000	0.0000	471.660	Intercept Only
2	0.3	0.0714	0.0916	428.470	A
2	0.5	0.0677	0.0880	430.173	B
2	2.5	0.0249	0.0461	449.912	I
3	-0.2	0.1051	0.1440	403.756	A B
3	0.0	0.1008	0.1399	405.694	A D
3	0.5	0.0907	0.1302	410.256	B I
4	-0.3	0.1324	0.1890	382.510	A B D
4	0.6	0.1130	0.1708	391.082	A B I
4	1.3	0.0968	0.1557	398.215	A D I
5	0.9	0.1305	0.2061	374.436	A B D I
5	1.4	0.1180	0.1947	379.841	A B D E
5	1.5	0.1168	0.1936	380.352	A B D F
6	2.4	0.1208	0.2163	369.620	A B D E I
6	2.6	0.1164	0.2124	371.466	A B D I J
6	2.7	0.1141	0.2104	372.416	A B D H I
7	4.0	0.1083	0.2246	365.703	A B D E H I
7	4.1	0.1067	0.2232	366.362	A B D E I J
7	4.2	0.1027	0.2197	368.018	B D E H I J
8	5.5	0.0982	0.2355	360.602	A B D E H I J
8	5.7	0.0931	0.2311	362.649	A B D E G H I
8	5.9	0.0871	0.2260	365.064	A B D E G I J
9	7.2	0.0820	0.2417	357.665	A B D E G H I J
9	7.4	0.0765	0.2371	359.814	A B C D E H I J
9	7.5	0.0747	0.2356	360.535	A B D E F H I J
10	9.0	0.0608	0.2445	356.323	A B C D E G H I J
10	9.2	0.0578	0.2421	357.460	A B D E F G H I J
10	9.4	0.0519	0.2374	359.689	A B C D E F H I J
11	11.0	0.0357	0.2453	355.961	A B C D E F G H I J

Cases Included 47 Missing Cases 0